CR 137481
AVAILABLE TO THE PUBLIC

RESEARCH REPORT

Battelle
Columbus Laboratories

(NASA-CR-137481) EFFECTIVENESS EVALUATION OF STOL TRANSPORT OPERATIONS (PHASE 2) Final Report (Battelle Columbus Labs., Ohio.) 204 p HC CSCL 01C

N74-21660

Unclas
G3/02 38091

204

BATTELLE'S COLUMBUS LABORATORIES comprises the original research center of an international organization devoted to research and development.

Battelle is frequently described as a "bridge" between science and industry — a role it has performed in more than 90 countries. It conducts research encompassing virtually all facets of science and its application. It also undertakes programs in fundamental research and education.

Battelle-Columbus — with its staff of 2500 — serves industry and government through contract research. It pursues:

- research embracing the physical and life sciences, engineering, and selected social sciences
- design and development of materials, products, processes, and systems
- information analysis, socioeconomic and technical economic studies, and management planning research.

505 KING AVENUE • COLUMBUS, OHIO 43201

I

FINAL REPORT

EFFECTIVENESS EVALUATION OF STOL TRANSPORT OPERATIONS (PHASE II)

by

David W. Welp, Ronald A. Brown,
David G. Ullman, and Mark B. Kuhner

February 8, 1974

Prepared under Contract No. NAS2-6889 by
BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

for

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

/

ACKNOWLEDGEMENTS

This effort was performed for the Ames Research Center under NASA Contract No. NAS2-6889. Appreciation is extended to Messrs. Norman Johnson, George Callas, Remus Bretoi, Clifford Burrous, and Ronald Hruby for their assistance provided. In addition, appreciation is extended to Mr. John Tucker, Vice President-Director of Flight Operations for Air California for his cooperation and the data provided in support of the simulation of Air California operations.

Contributors to the research program at Battelle's Columbus Laboratories were Messrs. David W. Welp, Ronald A. Brown, David G. Ullman, Mark B. Kuhner, Edwin S. Yarbrough, and James P. Loomis.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

LIST OF TABLES
(Continued)

LIST OF TABLES
(Continued)

LIST OF FIGURES

LIST OF FIGURES
(Continued)

Page

LIST OF FIGURES
(Continued)

EFFECTIVENESS EVALUATION OF STOL TRANSPORT
OPERATIONS (PHASE II)

By David W. Welp, Ronald A. Brown,
David G. Ullman, and Mark B. Kuhner
BATTELLE
Columbus Laboratories

INTRODUCTION

This report contains a description of four tasks accomplished under Amendment Number 3 of Contract NAS2-6889. This contract deals with Effectiveness Evaluation of STOL (Short Take-off and Landing) Operations. The first phase of the contract is described in Reference 1. The primary product of contract NAS2-6889 is a computer simulation program which models a commerical short-haul aircraft operating in the civil air system. The purpose of the program is to evaluate the effect of a given aircraft avionics capability on the ability of the aircraft to perform on-time carrier operations (see Figure 1). The program outputs consist primarily of those quantities which can be used to determine direct operating costs. These inlcude schedule reliability or delays, repairs/replacements, fuel consumption, cancellations, etc. Development of the simulation program continued during the second phase of the contract. More comprehensive models of the terminal area environment were added and a simulation of an existing airline operation was conducted to obtain a form of model verification. The capability of the program to provide comaprative results (sensitivity analysis) was then demonstrated by modifying the aircraft avionics capability for additional computer simulations.

Several additional tasks which fall under the contract objectives but which are not directly related to the computer simulation development were also accomplished during the second phase of the contract. The complete set of tasks for the second phase covered by Amendment Number 3 is listed below.

(1) Verify, expand, and exercise the effectiveness evaluation program. Verification was to be accomplished by simulating an existing air carrier short-haul operation. (Task 10)

(2) Examine the MLS (microwave landing system) coverage requirements for STOL operations. (Task 8)

(3) Determine the need for and application of INS (inertial navigation system) in future commercial STOL operations. In particular the applicability of SIRU (strapdown inertial reference unit), a redundantly configured strapdown system, was to be examined. (Task 9)

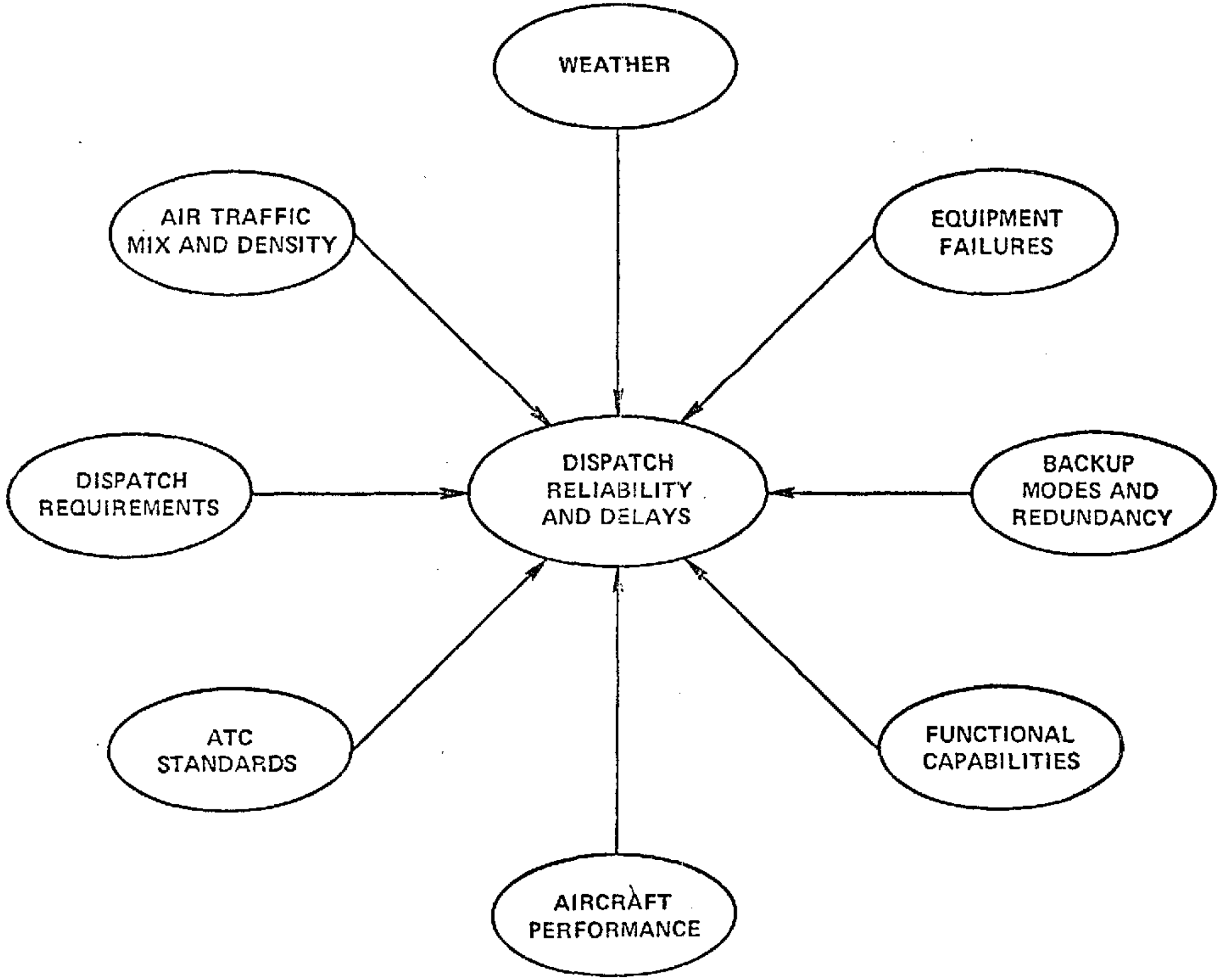


FIGURE 1. ELEMENTS OF THE STOL EFFECTIVENESS EVALUATION PROGRAM

(4) Examine the STOL operating experiments and their potential for providing airlines and aircraft manufacturers with data and technology needed to minimize direct operating costs and cost of ownership. (Task 11)

Each of these tasks is described separately in the same order listed above; first, in the Summary and Conclusions and then in the main body of the report.

SUMMARY AND CONCLUSIONS

Effectiveness Evaluation Program Simulation

Several improvements were made to the effectiveness evaluation program. These included:

(1) A terminal area ceiling and visibility model which distinguishes between Category I, II, and III approach conditions

(2) Addition of a more comprehensive approach and take-off queuing model

(3) A repair strategy more representative of airline operations.

A simulation of Air California's flight operations was conducted to obtain a data baseline and to provide a form of validation of the simulation program. Air California performance data were available in the form of gate departure delays and concellations. The amount of delay was separated into three time groups: 1-5 minutes; 5-15 minutes; and greater than 15 minutes. Gate departure delays were further separated by Air California into the following categories: maintenance, weather, equipment, passengers, fueling, ATC, late arrivals, and other.

In addition to the summary performance data described above, Air California provided equipment removal statistics on individual avionics items, data on the operating characteristics of their Boeing 737's, and general information about daily operating procedures.

The simulation results compared quite well with the Air California data. The only area of significant difference was in weather data. The weather model in the simulation, which utilized National Weather Service data, produced significantly more delays and cancellations than apparently experienced by Air California. The reasons for this difference are difficult to resolve because the Air California data represent a rather small statistical sample (2 years). In addition, their criteria for cancellations are not as straightforward as that used in the simulation (a flight was cancelled in the simulation if any departure delay exceeded 2 hours). Time and funds did not permit a search for and analysis of additional weather data from other airlines and government agencies.

The ability of the simulation program to provide comparative or sensitivity data was demonstrated through additional simulations in which

(1) The avionics complement aboard the Air California 737's was augmented to provide a Category II and III approach/land weather capability.

(2) Differing repair strategies were used.

(3) The flight schedule was varied.

The results showed the impact of these changes, primarily on schedule reliability and maintenance requirements. The addition of a Category III avionics capability reduced delays and cancellations, but at the expense of significantly more hardware failures. It was also shown with Category III equipment that the schedule reliability is sensitive to repair strategy. Performance can be significantly improved if equipment required for low visibility approach and takeoff is not repaired during the daily flight operations unless weather forecasts dictate the potential need for the capability.

The computer simulation tool has reached a stage of development which will allow its use for assessment of the impact of avionics capability on airline performance. Each application will very likely require some probram modification or modeling improvement in the specific avionics area which the user is interested in evaluating. However, it has been demonstrated that the model provides a reasonable representation of an actual airline operation and is an excellent vehicle for analysis of the sensitivity of performance to avionics parameters.

MLS Coverage Requirements for STOL Operations

The greatest demand on azimuth MLS coverage for STOL operations will likely occur at high density airports equipped with parallel independent runways. The presence of parallel runways effectively eliminates half the available airspace from normal maneuvers for any given runway. At the same time, maximizing capacity at the high density airports will be a major concern. In the future (1985 - 1990 time period) this will imply precise time of arrival control and a minimum time on the common path for the slower speed aircraft. The coverage required under these circumstances depends on:

(1) The amount of time adjustment which must be accommodated within the MLS coverage

(2) The position uncertainty at the entrance to MLS coverage

(3) The common path length

(4) The aircraft maneuver constraints near the common path gate.

An analysis of each of the above factors was accomplished to determine the impact of each on MLS coverage requirements. Based on this analysis, the following conclusions were drawn regarding the three discrete azimuth coverages proposed by the RTCA Subcommittee 117. (The three coverages which they considered were ±20 degrees, ±40 degrees, and ±60 degrees.)

(1) A coverage of ± 60 degrees does not appear to offer a significant advantage over ±40 degrees coverage.

(2) A coverage increase from ±20 to ±40 degrees can significantly degrease the required STOL common path length if a large (±60 seconds) time adjustment capability is required.

(3) A large time adjustment capability within MLS coverage requires excessive common path lengths for any of the coverages. Thus, there is advantage in attempting to to minimize this required capability with some form of control outside the MLS coverage.

(4) A coverage of ±20 degrees is adequate if the disadvantage of longer common paths can be compensated with altitude separation on the final path.

(5) A coverage of ±20 degrees is adequate if a time of arrival control authority on the order of ±15 seconds is adequate. A ±15 second requirement is representative if time of arrival is controlled prior to reaching MLS coverage utilizing VOR/DME's as navigation aids.

Application of INS to STOL

An industry survey of the present and forecasted INS developments and the need for INS aboard STOL or other short-haul aircraft was conducted. The results of that survey are as follows.

Gimballed inertial navigation systems presently in service have the following characteristics.

Replacement Cost	\$85K - \$110K
Performance	Better than one mile per hour
Reliability	1000 - 1500 hours MTBF
Maintenance Cost	\$2.50 - \$3.00 per system hour. This represents approximately \$12,000 per year for each installed INS.

The cost of gimballed systems will not improve significantly. It is highly unlikely that any new gimballed systems could sell for less than \$75,000. This conclusion is generally accepted by all of the INS manufacturers consulted, even those heavily committed to gimballed systems.

The airlines feel that INS is very expensive both for initial buy and recurring costs. Maintenance is difficult because of the system complexity and spares are expensive. Airlines will not purchase INS for short-haul unless its cost and maintenance requirements are competitive with the equipment being replaced.

STOL aircraft may require Schuler-tuned attitude information rather than a continuous gravity erection system to satisfy verticality requirements in the terminal area. The potential for more maneuvering and shorter periods of level flight prior to landing for a STOL aircraft may prohibit the the use of the conventional vertical gyro because of the large errors that it can develop under maneuvering conditions.

INS offers significant benefits in terms of performance, flexibility, and safety. Safety is enhanced primarily in the terminal area not only as described above for Category III operations, but for any IFR conditions, particularly at ill equipped airports. Flexibility is derived from the fact that INS represents a completely self-contained navigator which can function accurately, independent of any external navigation aids. The INS also offers flight control management through its computer and smooth, accurate, coupled flight control performance freeing the flight crew for other critical flight duties. The safety features are particularly important because a significant proportion of flight accidents occur in the terminal area when aircraft wander from the prescribed flight path. STOL aircraft operating from both the small, ill equipped airports and the high density hubs should find the flexibility offered by INS particularly attractive.

Strapdown systems offer a significant reduction in price and reliability. However, a conventionally configured strapdown system will still suffer many of the drawbacks of gimballed systems. The line replaceable unit will still be a complete inertial package (3 axes of gyros and accelerometers).

Fail-operational capability will still require three complete systems, thereby reducing the reliability of the fail-operational condition by a factor of three over the reliability of a single system. A single system will still likely be at least a factor of two more expensive than a non-redundant set of instruments that could be replaced. Several INS manufacturers are currently developing strapdown systems. All of these reflect conventional configurations with a price goal of $35K-$50K.

An integrated redundant strapdown system such as that being developed by The Charles Stark Draper Laboratory for NASA/Ames can be a real breakthrough for commercial INS making them cost effective for short-haul airline use. The primary features of such a system which could make it particularly attractive are:

(1) A high level of redundancy with a reduced level of duplication,
(2) reliable fault isolation reducing the probability of unverified removals (approximately 40 percent of present removals are unverified),
(3) on-line correction for stable bias shifts normally requiring a system removal, and
(4) line replaceable components (gyros and accelerometers) rather than complete systems.

Items 2, 3, and 4 are generally very difficult or impossible to achieve with conventional non-redundant systems because of the inability to reliably detect and isolate component failures.

Examination of STOL Operating Experiments

The purpose of this task was to examine the STOL Operating Experiments from the airline viewpoint to determine the ability of those experiments to impact cost of ownership, function reliability, and return on investment. The following conclusions were reached after analysis of the experiment plan and the results from the effectiveness evaluation program simulation.

(1) The experiment plan is responsive to the stated objectives.

(2) The experiments influence airline cost to the extent that they optimize in-flight performance with minimum complexity.

(3) Implementing the resultant technology will almost certainly require more avionics complexity than exists on present short-haul aircraft. Short-haul aircraft such as 737's or DC-9's presently carry a very austere set of avionics.

(4) This increased complexity will adversely affect direct operating costs because of less overall equipment reliability causing greater maintainability costs.

The computer simulation results vividly showed the large increase in maintenance requirements due to increased complexity. The increased complexity can be cost effective, however, if there are concurrent developments to achieve:

(1) Longer "effective" equipment MTBF

(2) Elimination of unverified removals

(3) Shorter mean maintenance delays

(4) Reduced spares costs.

There does not appear to be any development activity, either within the Equipment Plan or in other STOL avionics programs, aimed at achieving these objectives.

EFFECTIVENESS EVALUATION SIMULATION PROGRAM

The STOL effectiveness computer simulation program was developed to be a tool for assessing the impact of various avionics configurations on commercial airline operations. The program simulates an aircraft operating over a defined commercial route network and evaluates the overall effect of the various elements which influence a typical airline operation. The first phase of the program development was accomplished during the contract period from May, 1972, to February, 1973, and is reported in Reference 1. Improvements and modifications accomplished during Phase II are described in this report.

The program measures of performance are those parameters which can be related (through simple algebraic functions) to direct operating cost. These include (but are not limited to) delays, dispatch reliability, cancelled flights, diversions to alternate airports, and fuel consumption.

The program utilizes the Monte Carlo method for the statistical analysis. The following basic steps are involved in the simulation.

(1) The route network must be defined in terms of the flight path, time schedule, and airport layout.

(2) That network is "flown" (equations of motion are integrated) once within the program to determine nominal flight and taxi times.

(3) The probability distributions for uncertain flight events must be described. These include distributions for wind, ceiling and visibility, queuing, equipment failure, and other statistical events which have a significant impact on a flight schedule. A major portion of the program development has been devoted to acquiring these distributions and determining appropriate logic to describe what procedure is used when events occur.

(4) With the above information the Monte Carlo evaluation can be accomplished. A one-day flight schedule is simulated by sequentially drawing random numbers from the flight event distributions and taking the action dictated by the outcome of each event. The result for one day is a history of events and delays for the individual flight legs. Numerous days are simulated to determine probability distributions of the events and delays.

Some of the more important factors which affect the simulation in its present status are as follows.

(1) Equipment Failures. Failures can degrade performance, limit the ability to cope with adverse weather, and cause delays while repair or replacement takes place between flight legs.

(2) Maintenance Time. The statistical distributions for time to repair or replace determine the length of delays due to equipment failure.

(3) Repair Strategy. Certain equipment need not be repaired at the first stop after a failure occurs. The impact of these failures can be minimized by deciding to repair or replace based on weather conditions and forecasts, gate time at the next stop, time before reaching a lengthy stop or major repair facility, etc.

(4) Weather. Several weather characteristics affect the simulation. The ceiling and visibility conditions in the airport vicinity affect the ability to land and the length of waiting queues. Local winds determine the active runway and en route winds affect time of flight and fuel consumption.

(5) Fueling. The method of fueling can have an impact on the schedule. The aircraft can fuel at every stop or can load more fuel once every two to four stops. In addition uncertainties such as adverse weather ahead or airborne holding can cause unscheduled fueling.

(6) Passenger and cargo loading delays.

(7) Landing and take-off queues.

(8) Nominal aircraft performance. This refers to the aircraft acceleration, climb and descent rates, speed range, fuel flow, etc.

(9) Schedule and flight paths.

Figures 2 to 8 are flow diagrams of the most significant steps in the program.

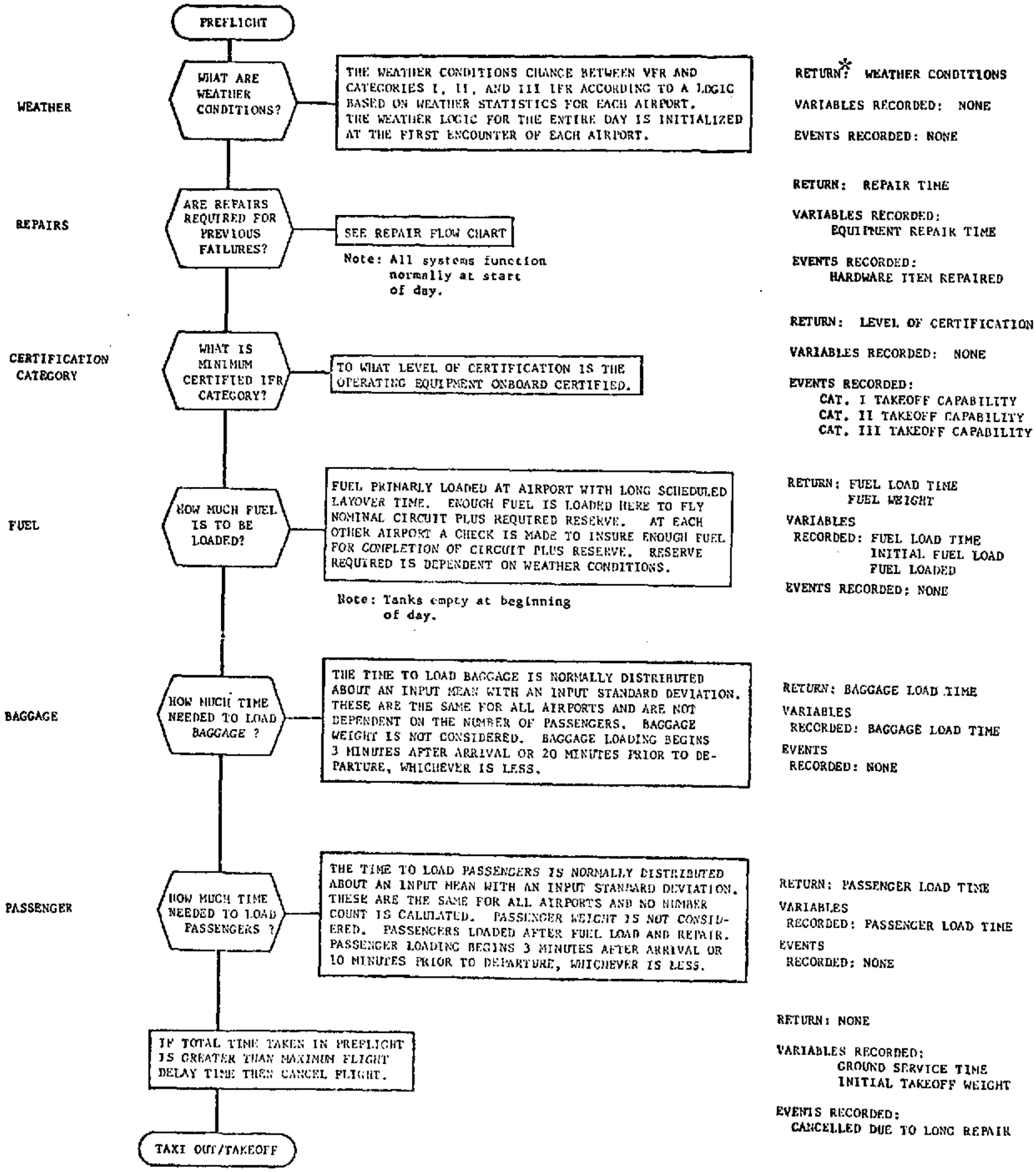
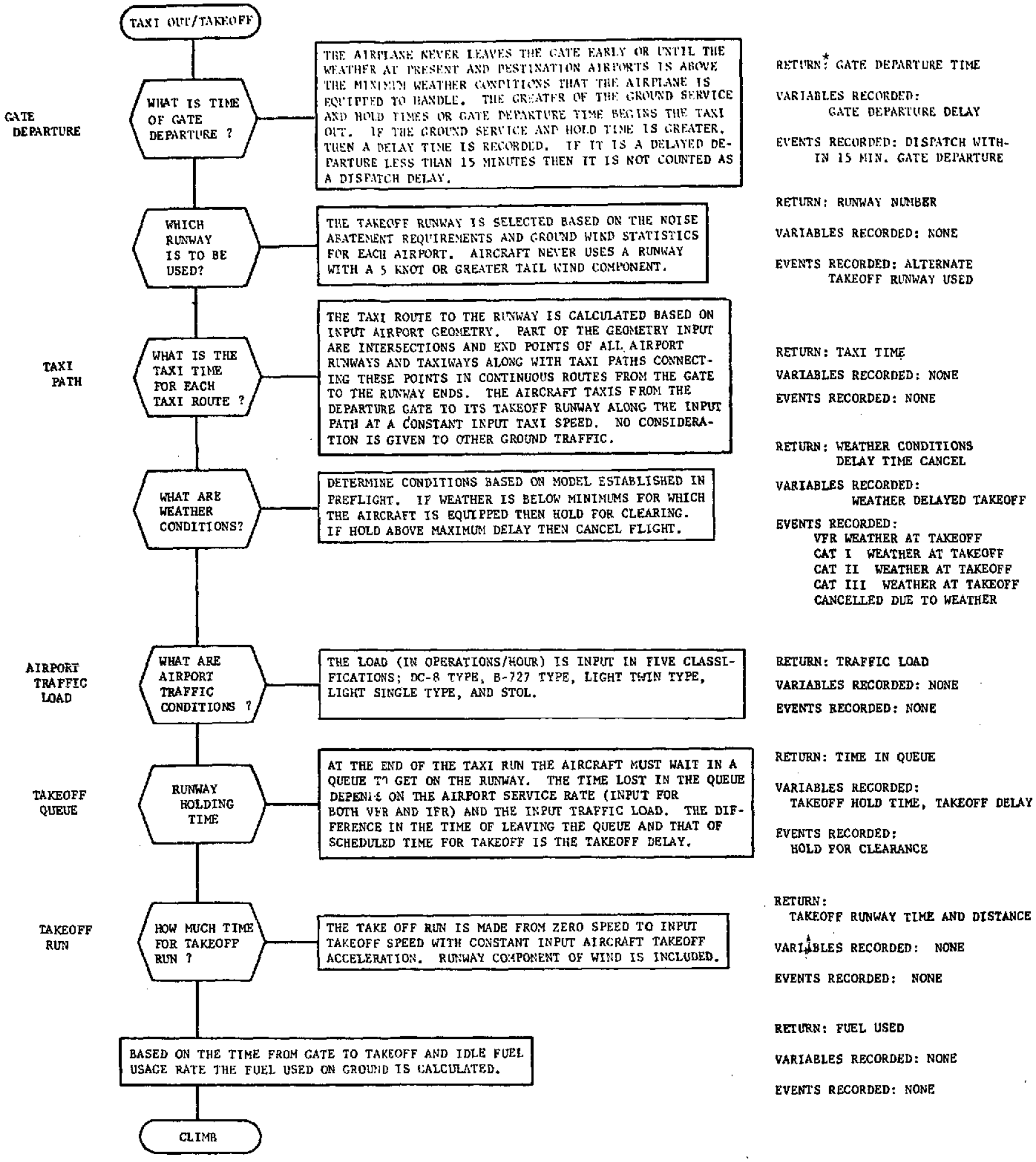


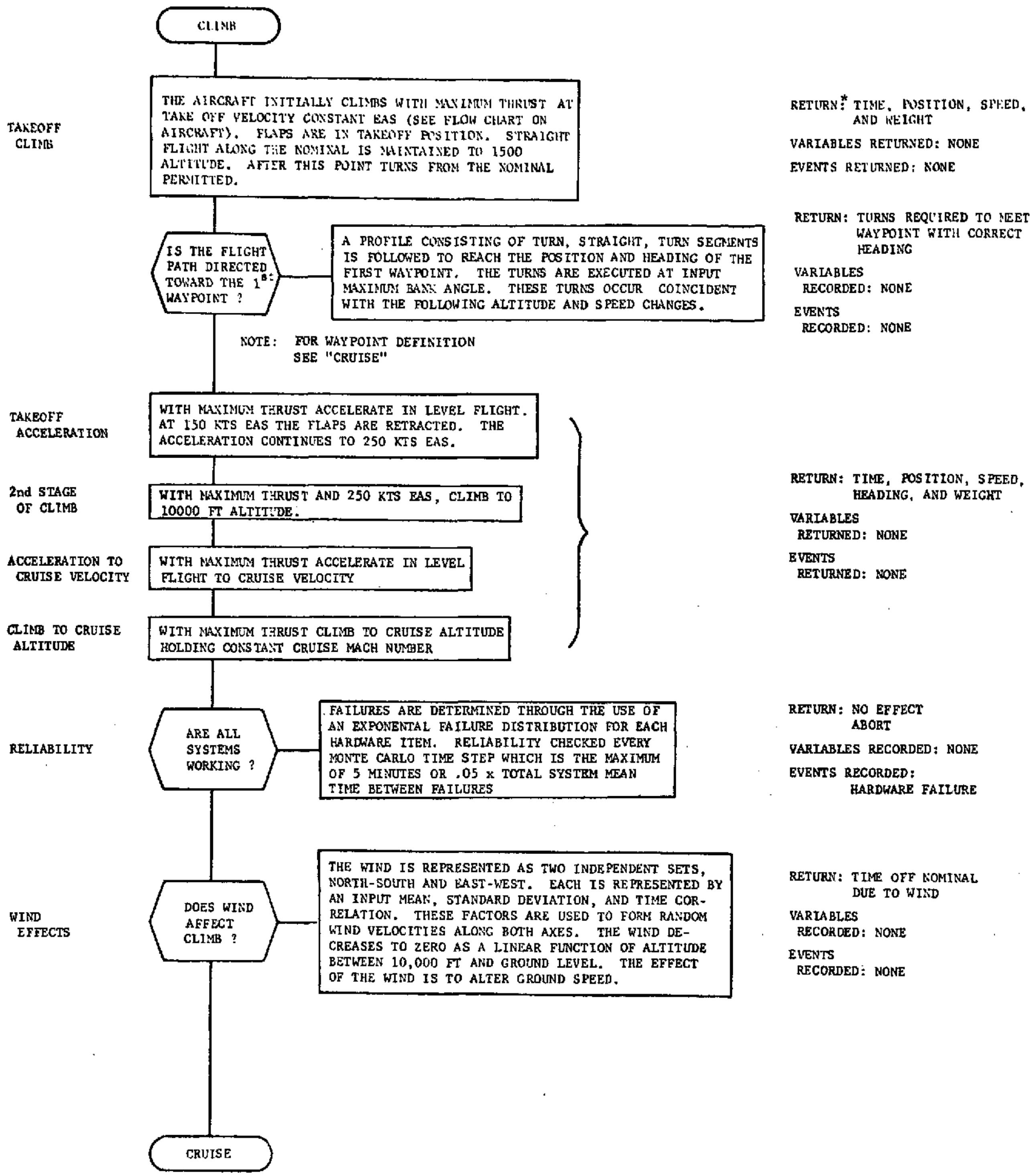
FIGURE 2. PREFLIGHT PROCEDURE

* Variables returned to the main program.



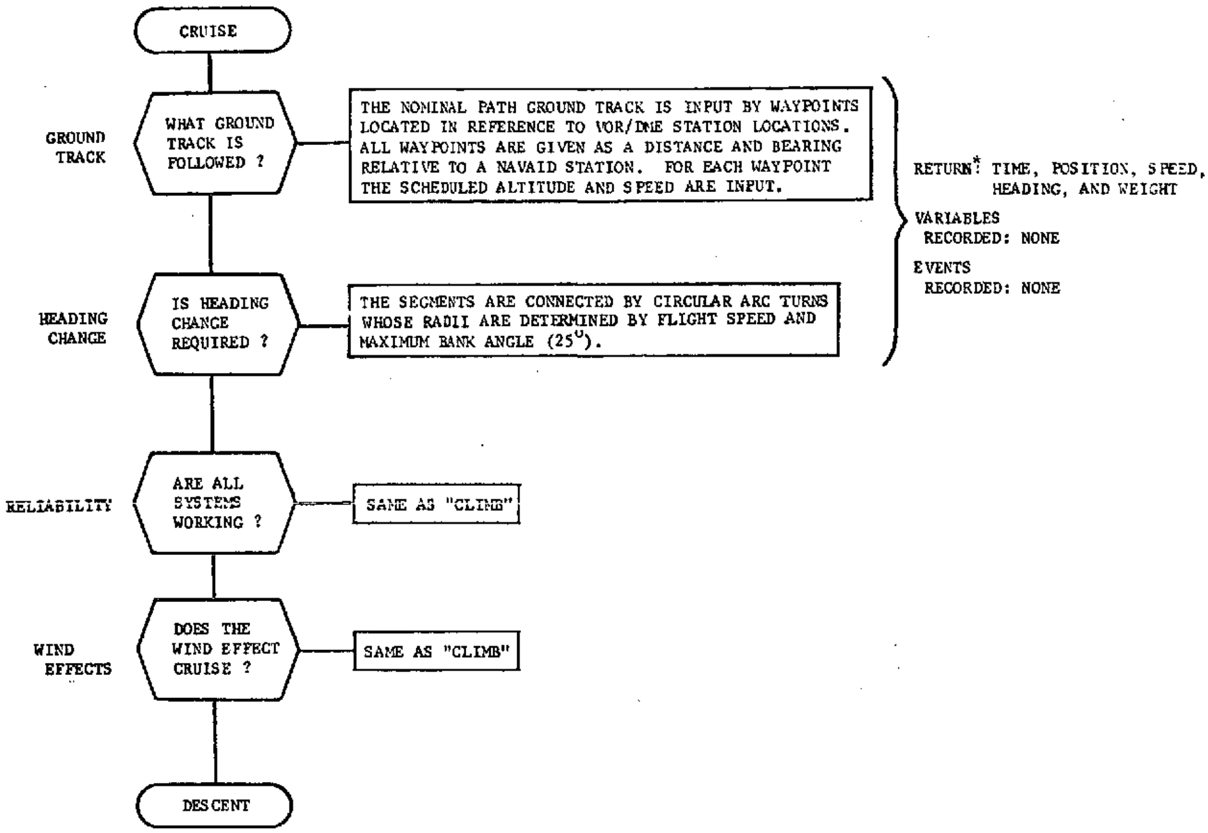
* Variables returned to the main program.

FIGURE 3. TAXI/TAKE OFF PROCEDURE



*Variables returned to the main program.

FIGURE 4. CLIMB OUT PROCEDURE



* Variables returned to the main program.

FIGURE 5. CRUISE PROCEDURE

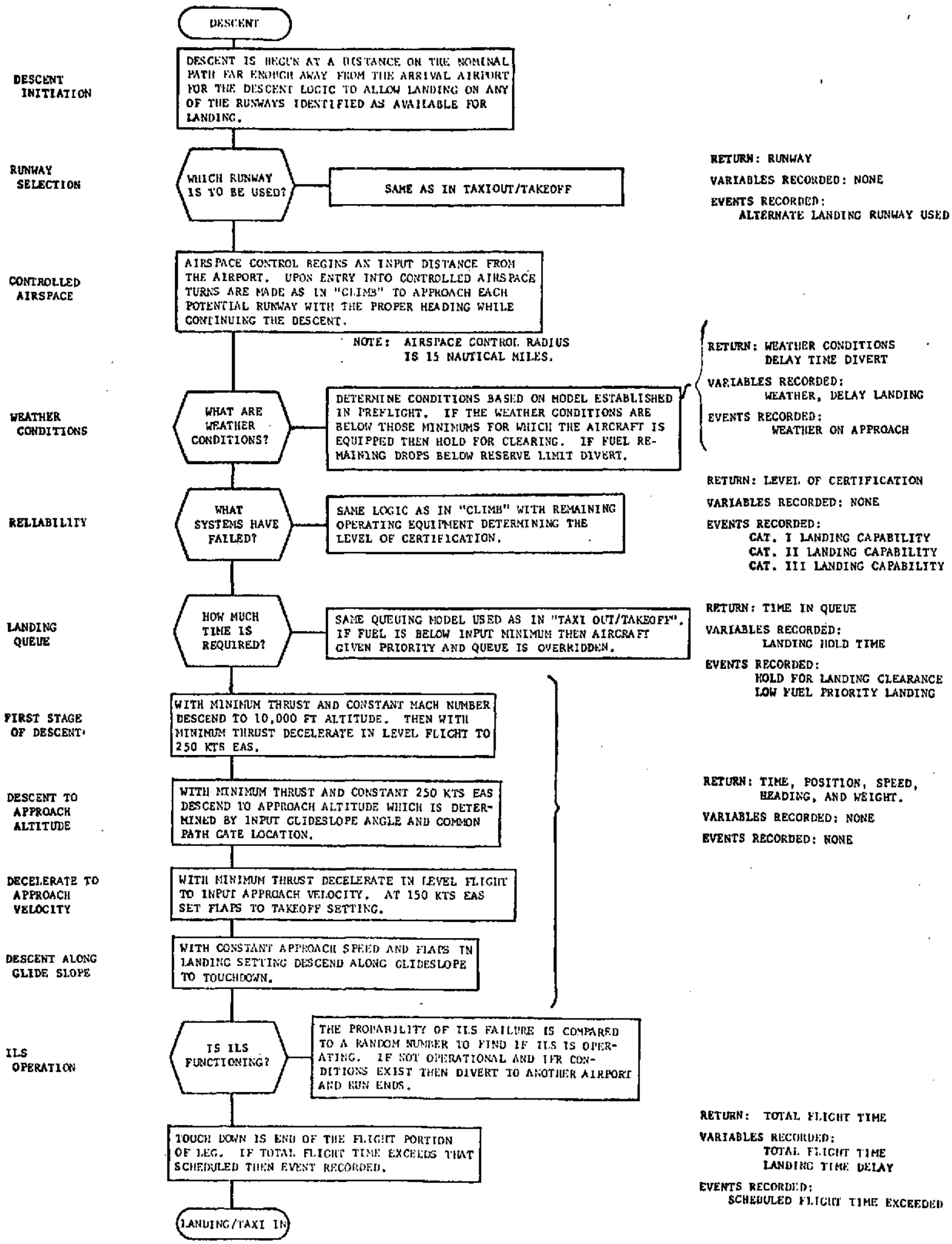


FIGURE 6. DESCENT PROCEDURE

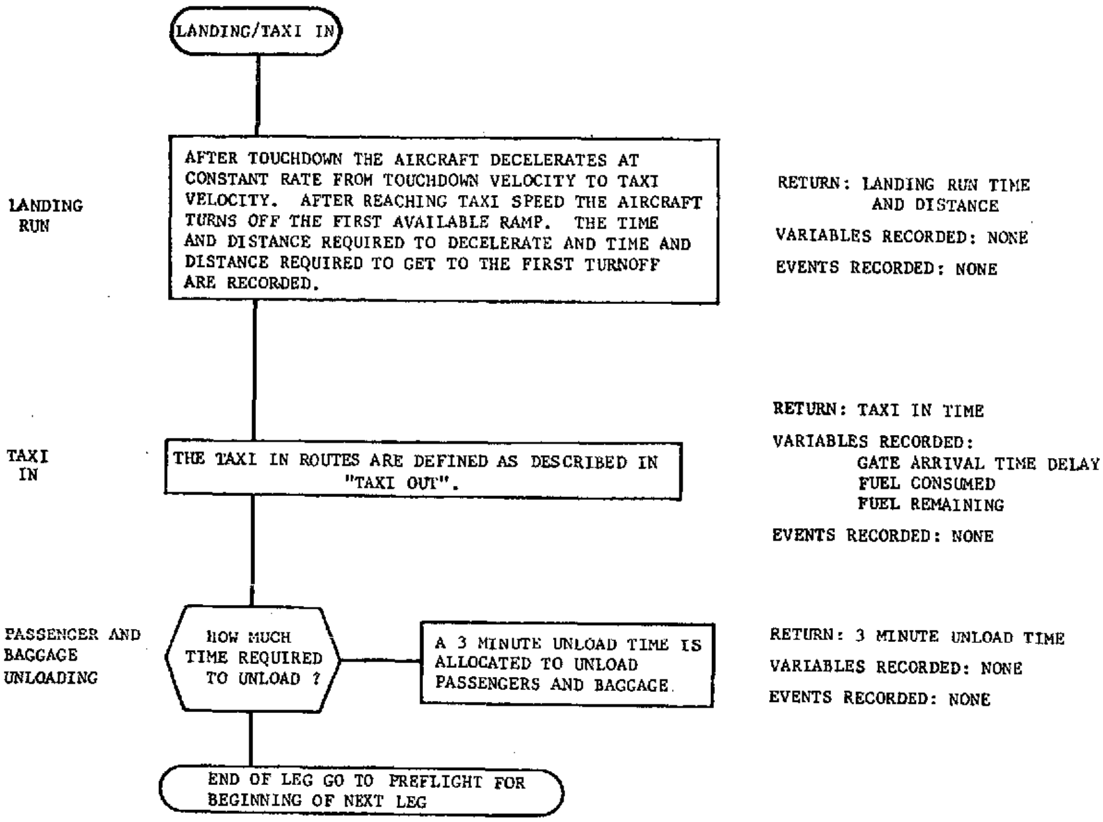


FIGURE 7. LANDING/TAXI PROCEDURE

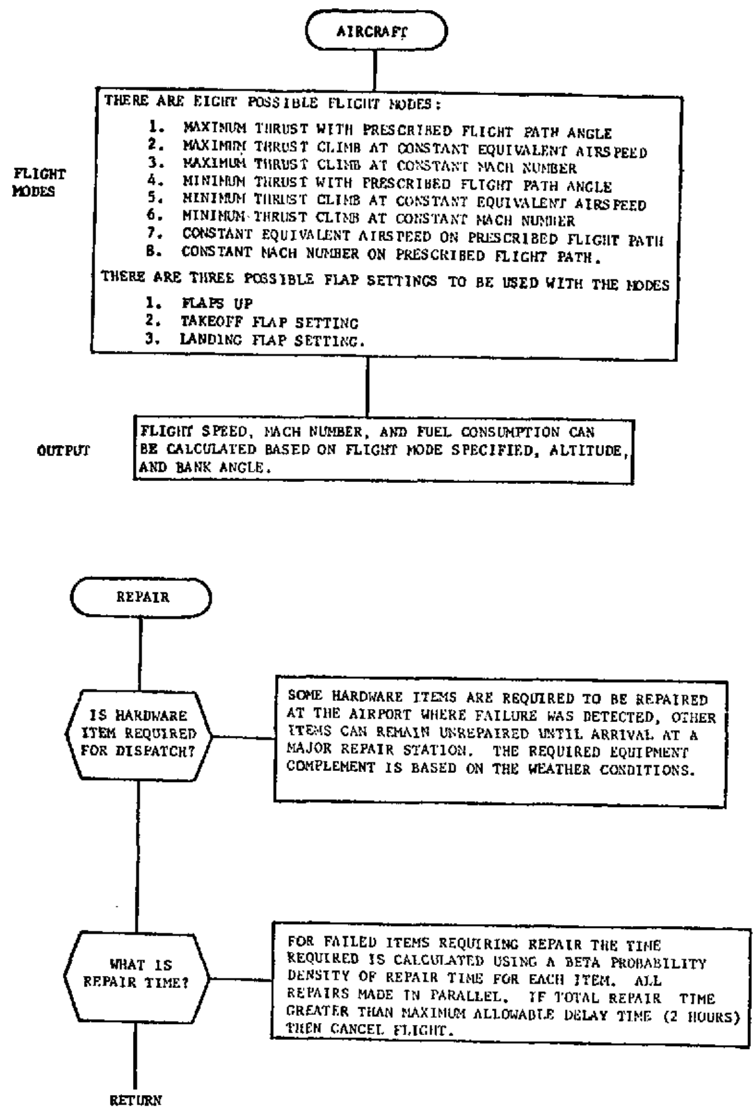


FIGURE 8. AIRCRAFT AND REPAIR PROCEDURES

Program Modifications During Phase II

Several improvements and modifications were made during Phase II. Most of these are described under the discussion of the Air California Simulation in the next section. Those not directly related to that simulation are described below.

Ceiling and Visibility.- Weather data in the vicinity of San Jose Municipal, Sacramento Executive, and Orange County Airports were obtained from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA). Those airports are the ones simulated during the Phase I development. The data were reduced to probabilities of VFR and Category I, II, and III ceiling and visibility conditions at each airport. In addition data were found in climatological summaries supplied by the National Climatic Center on the expected duration of Category II and III conditions in the Los Angeles and Oakland areas. These data were used to develop and incorporate a Markov Chain model of approach and take-off weather conditions. The model and data are described in detail in Appendix A.

Local Wind.- The data supplied by NOAA also contained statistical distributions of wind intensity and direction for each of the three airports. These data were incorporated in the program to provide the basis for selection of the active runway for each approach and take-off. Each airport has a primary runway, usually dictated by noise abatement considerations. Alternate runways are utilized when tailwinds on the primary runway exceed 5 knots.

Landing and Take-off Traffic Delay.- A relatively simple traffic delay model was utilized in the initial program development. A more comprehensive queuing model which was a part of Battelle's Airport Integrated Design System (AIDS) developed for the FAA, was utilized during Phase II. AIDS is a set of computer programs, implemented with interactive graphics, which can be used for the analysis of runway usage and incurred delays (Airspace model), gate demand and delays (Airside model), and ground terminal area requirements (Landside model). In one of several modes of operation, the Airspace model can be used to produce runway service rate and diurnal delay pattern. The inputs are traffic mix and demand as a function of time of day. The outputs utilized in the STOL simulation program are the mean value and standard deviation of the delay versus time of day. It is assumed that at any given time, the probability distribution of delay is Gaussian, described by the mean and standard deviation. The use of the model is discussed further in the next section.

Air California Simulation

One of the objectives of Task 10 was to provide some form of validation of the simulation program. The method chosen was to simulate an existing airline operation. Air California was contacted and they agreed to support the simulation by making their operations and maintenance data available.

Air California is a short-haul intrastate carrier operating Boeing 737's. They have service to Santa Ana (Orange County), Ontario, San Diego, San Jose, Oakland, San Francisco, Palm Springs, and Sacramento. Air California provided the following information:

(1) Data on the operating characteristics of the 737,

(2) Lists of equipment aboard the 737 and the minimum equipment list from the pilot's handbook,

(3) Monthly premature removal reports for the avionics equipment,

(4) Maintenance performance reports, and

(5) Operating statistics.

The data available covered approximately two years' operations for seven Boeing 737's. Tables 1 and 2 are samples of the maintenance and operating statistics, respectively. Table 3 summarizes some of the most pertinent data from those tables. There were no data on duration of delays, with the exception of maintenance delays. The 737 operating characteristics were used to modify the existing aircraft simulation so that it matched the 737 performance. The equipment lists and minimum equipment requirements were utilized as input data on aircraft avionics complement. The premature removal reports provided the data from which the mean time between unscheduled removals (MTBUR) for individual equipment could be determined.

Fueling was based on three considerations:

(1) Minimum fuel required. This is the sum of the minimum trip fuel (2000 lb), the FAR 121 required residual fuel for 45 minute cruise (4000 lb), and starting and taxi fuel (400 lb). This gives a minimum load of 6400 lb.

TABLE 1. AIR CALIFORNIA B-737 MAINTENANCE PERFORMANCE REPORT FOR THE PERIOD JULY, 1971 - JUNE, 1972

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
Number of Aircraft in Service	8	8	8	8	8	8	8	8	8	7	7	6
Total Hours Flown	1391	1397	1339	1532	1470	1500	1400	1295	1364	1279	1342	1264
Number of Departures	2212	2248	2177	2420	2370	2509	2387	2216	2287	2180	2254	2181
Daily Utilization Hours	5:36	5:38	5:34	6:11	6:08	6:03	5:38	5:35	5:45	6:05	6:11	6:01
Enroute Checks Performed	183	124	118	76	76	169	168	160	157	143	140	140
Preflight Checks Performed	113	121	121	164	164	68	65	63	62	58	68	57
Service Checks Performed	8	9	8	9	9	8	7	7	6	4	6	6
Maintenance Checks Performed	2	2.25	2	2.25	2.25	2	1.75	1.75	1.50	1	1.50	1.5
Cancellations Caused by Maintenance	4	2	1	9	9	1	4	1	3	2	3	2
Total Hours Delayed by Maintenance	9:23	9:26	4:54	15:16	13:53	18:21	14:34	14:05	16:17	7:33	21:42	17:27
Average Length of Maintenance Delays	20min	21min	11min	30min	27min	24min	27min	31min	30min	16min	35min	23min
Hours Flown per Maintenance Delay	50	52	52	51	47	33	44	48	41	44	36	27
Maintenance Delays per 1000 Flight Hours	20	19	19	20	21	31	23	21	24	23	28	36
Maintenance Delays per 1000 Departures	13	12	12	12	13	18	13	12	14	13	16	21
Delays Caused by Maintenance	28	27	26	39	21	46	32	27	33	29	37	44
Number of Delays Following Maintenance	0	0	0	8	2	4	3	3	3	3	5	6
Number of Mechanical Delays	23	21	18	29	26	42	23	20	29	22	31	31
Number of Avionics Delays	1	5	6	2			4	3	1	1	1	5
Number of Electrical Delays	4	1	2	0	3		2	1	0	3		2
Maint. Cancellations in % of Total Departures	0.18%	0.09%	0.5%	0.37%	0	0.04%	0.17%	0.05%	0.13%	0.09%	0.13%	0.09%
Maint. Delays in % of Total Departures	1.27%	1.30%	1.19%	1.24%	1.30%	1.83%	1.34%	1.22%	1.44%	1.33%	1.64%	2.02%
PERCENT OF DEPARTURES CANCELLED OR DELAYED FOR MAINTENANCE	1.45%	1.29%	1.24%	1.61%	1.30%	1.87%	1.51%	1.27%	1.57%	1.42%	1.77%	2.11%

TABLE 2. AIR CALIFORNIA B-737 OPERATING STATISTICS FOR THE PERIOD JULY, 1971 - JUNE, 1972

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
Departures Scheduled	2220	2251	2178	2444	2383	2581	2439	2233	2313	2180	2254	2180
Departures Made	2212	2248	2177	2420	2370	2509	2387	2216	2287	2180	2256	2181
SCHEDULE PERFORMANCE	99.6%	99.8%	99.9%	98.8%	99.4%	99.1%	97.8%	99.2%	98.8%	100%	100.1%	100%
Maintenance Cancellations	4	2	1	9	0	1	4	1	3	2	3	2
Weather Cancellations	0	0	0	1	0	1	9	4	0	0		
Equipment Cancellations	1	4	6	4	2	3	3	0	4	3	4	1
Other Cancellations	1	0	0	4	3	--	--	1	0	0	2	3
TOTAL CANCELLATIONS	6	6	7	18	5	5	16	6	7	5	9	6
Passengers Carried	80,352	88,457	75,973	80,169	88,475	85,273	75,500	77,822	88,606	82,781	89,947	94,446
Available Seat Miles (000)	53,276.2	53,968.7	51,414.2	56,780.6	55,603.9	58,015.3	53,845.1	49,918.2	51,533.6	50,568.2	52,677.0	51,580.8
Revenue Pax Miles (000)	28,274.1	31,120.0	26,858.8	28,595.6	30,012.8	30,412.8	26,804.7	27,579.4	31,645.9	29,620.8	32,233.5	33,699.3
LOAD FACTOR	52.2%	57.7%	52.2%	50.4%	54.0%	52.4%	49.8%	55.2%	61.4%	58.6%	61.2%	65.3%
ON-TIME PERFORMANCE	69.9%	69.7%	70.7%	63.4%	59.6%	52.9%	55.7%	57.1%	57.4%	68.0%	65.9%	60.0%
1-5 Minute Delays	366	369	368	392	350	452	373	319	408	393	399	400
5-15 Minute Delays	210	187	219	322	309	455	346	334	302	239	230	282
Over 15-Minute Delays	90	92	63	190	290	317	335	293	251	365	131	199
TOTAL DELAYS	666	649	640	904	949	1224	1054	946	961	697	760	881
Maintenance Delays	28	27	26	30	31	46	32	27	33	29	37	44
Weather Delays	0	5	1	10	20	7	52	43	15	1	--	--
Equipment Delays	0	7	4	8	2	7	7	3	6	7	12	13
Passenger Delays	49	78	41	33	28	53	9	22	20	23	36	23
Fuel Delays	17	6	9	15	14	13	6	9	6	10	14	8
ATC Delays	9				3	3	1	4	1	0	--	1
Late Arrivals	444	421	403	605	671	832	768	675	707	437	451	563
Other Delays	119	104	162	203	280	263	179	163	173	190	210	227

TABLE 3. SUMMARY OF AIR CALIFORNIA OPERATING PERFORMANCE (JULY, 1971 - JUNE, 1973)

Gate Departure Delays	
1 - 5 min	17.1%
5 - 15 min	15.2%
> 15 min	10.3%
Sources of Delay	
Maintenance	1.48%
Passengers	1.47%
Fuel	.41%
Weather (Year Round)	.42%
(November-March)	.78%
Late Arrivals	29.42%
Other	8.69%
Mean Maintenance Delay	26.5 min
Cancellations	
Weather	0.027%
Maintenance and Equipment	0.236%

(2) Maximum gross weight. Maximum gross weight is about 115,000 lb and is dependent on runway length and environmental conditions. However, Air California seldom loads their aircraft over 100,000 lb. Maximum fuel weight is 24,000 lb.

(3) Fueling costs at each airport. The price of fuel can vary by as much as 50 percent at the airports served by Air California. The price at some stations is volume dependent and many have a minimum order requirement.

The third consideration influenced the simulation to the extent that scheduled fueling occurred at as few airports as possible.

A one day flight schedule was set up based on a one day average of the Air California seven aircraft flight itinerary. Figure 9 shows the Air California itinerary for an average day. Each bar represents block time (gate to gate time). The open spaces represent time at the gate. Many of the stops are as short as 10 minutes. This schedule has the following average conditions:

(1) 14.7 flight legs per day

(2) 39.3 minutes block time per leg

(3) 23.3 minutes gate time per leg

(4) 9.33 hours block time per day.

The last row on Figure 9 shows the schedule that was set up to be representative of the Air California schedule for use in the simulation. This simulated schedule has the following average conditions:

(1) 15 flight legs per day

(2) 35 minutes block time per leg

(3) 21.8 minutes gate time per leg

(4) 8.45 hours block time per day.

Note that this schedule utilizes the three airports simulated during Phase I (San Jose, Sacramento, and Orange County) plus Ontario. Ontario was added to provide several short legs (15 minutes from SNA to ONT). The shortest leg possible with only the three initial airports was 25 minutes from San Jose to Sacramento. The weather data for Orange County were also used to represent the weather at Ontario.

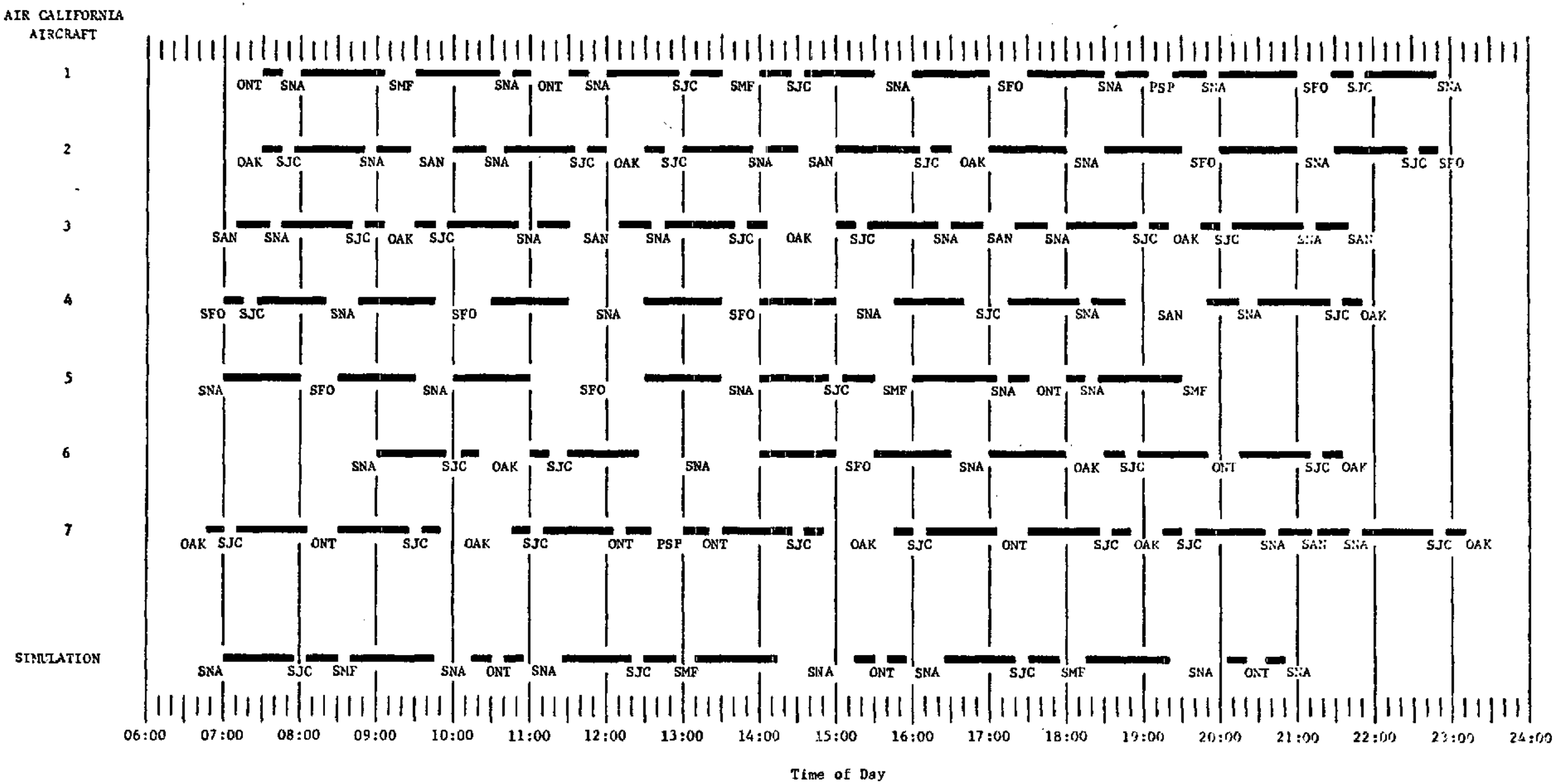


FIGURE 9. COMPARISON OF AIR CALIFORNIA SCHEDULE
AND SIMULATION SCHEDULE

Information on traffic delays at the airports to be simulated was obtained from Air California and the airport tower personnel at Orange County and San Jose. The consensus from all consulted was that traffic congestion delays were minimal at all of the airports to be simulated. Of these, Orange County was the busiest. Thus, the congestion delay at this airport was analyzed with the Battelle AIDS program described in the previous section.

Based on FAA data and limited data from the Orange County Airport the average number of daily operations is 156 commercial carrier, 323 light twin, and 1,377 single engine. The airport has two parallel runways separated by 500 feet. One is 5,700 feet long and the other is 2,888 feet long. During VFR operations the runways are used virtually as independent runways. Approximately 60 percent of operations are on the shorter runway and they are almost all single engine light aircraft. On this basis the demand on the longer runway was described as 156 operations at 120 knots, 323 at 95 knots, and 252 at 85 knots. The demand pattern was set approximately uniform from 0700 to 2000 hours. Figure 10 shows the mean arrival delay predicted by the AIDS program. No further analysis of this or the other airports was attempted because of the almost insignificant traffic delays at these airports. Traffic delays are generally not worse under IFR conditions because most of the light aircraft are not flying under those conditions.

Table 4 shows the equipment complement used in the simulation along with the dispatch requirements. Some of the equipment is required for each aircraft dispatch, whereas, other equipment on the minimum equipment list can wait a few flight legs until the aircraft reaches one of the airline repair stations. Orange County was designated as the repair facility for purposes of the simulation. Thus, as an example, the aircraft cannot be dispatched unless two attitude reference systems are operable. The fourth column lists the equipment which must be operable to accomplish a Category I landing.

Table 5 shows the results for a simulation of 5,000 days of the schedule shown on the bottom row of Figure 9. This table is an accumulation of data for all 15 flight legs. In addition to this summary page, a typical computer output has a similar page for each of the flight legs. The output is separated into two categories; continuous variables on the top half of the table and discrete events on the lower half. Following is a description of each of the columns for the continuous variables.

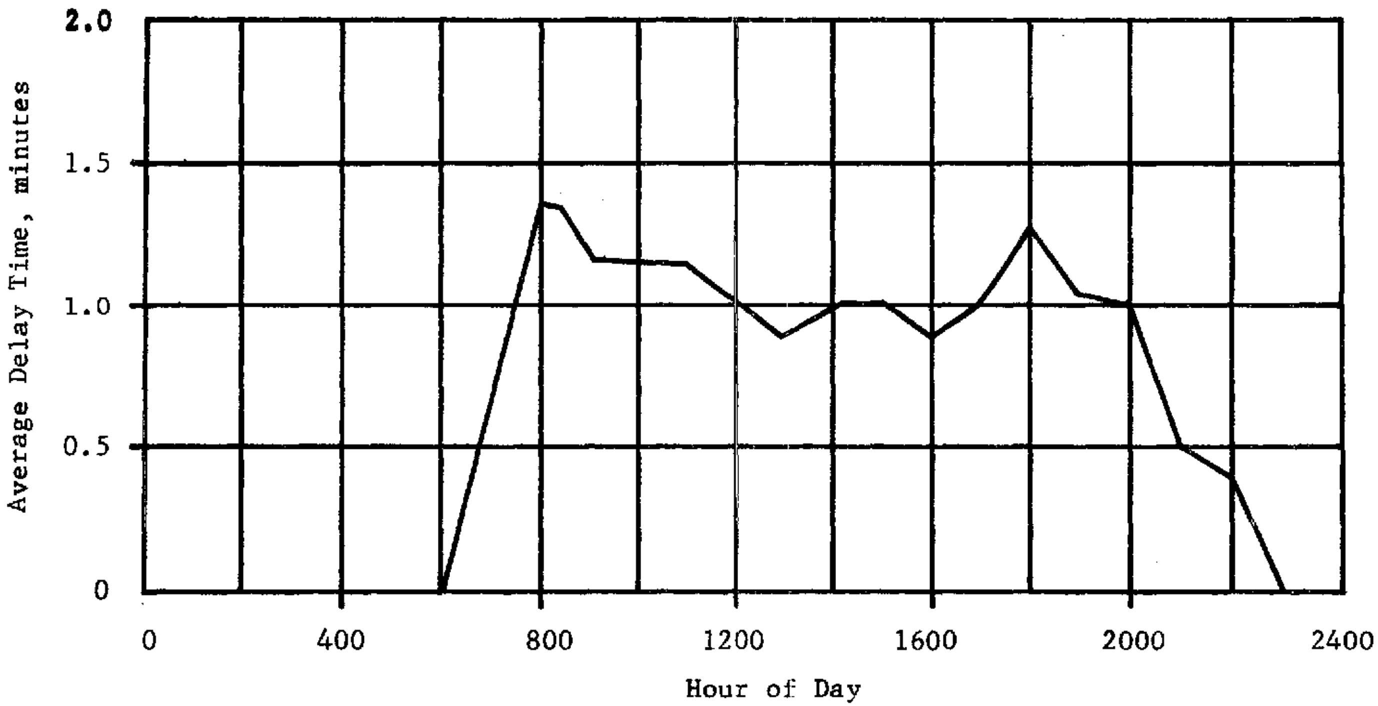


FIGURE 10. AVERAGE ARRIVAL DELAY ON MAIN RUNWAY AT SANTA ANA AIRPORT

TABLE 4. CATEGORY 1 EQUIPMENT REQUIREMENTS

Item	Qty	Req'd for Dispatch	Fix @ 1st Rep. Stn.	Cat. 1
Flight Director	2			
Flight Control	1			1
Speed Control	--			
Primary Compass	2	2		
Backup Compass	1		1	
Attitude Reference	3	2	3	1
Air Data Computer	1		1	
Altimeter	2	2	2	
Airspeed	2	2		
VHF Comm. Receiver	2	2		
VHF Nav. Receiver	2	1	2	1
Marker Beacon Receiver	1			
DME	2	1	2	
Radio Altimeter	--			
ATC Transponder	2	1	2	
Weather Radar	1		1	
Flight Recorders	1		1	
Flight Interphone	1	1		
Instrument Comp/Warn	1			
Additional Avionics	2	1	2	
Air Conditioning	1	1		
Oxygen	1	1		
Hydraulics	2	2		
Electrical System	2	2		
Engines	2	2		
Additional Mech. Items	2	2		

TABLE 5. RESULTS OF SIMULATION OF AIR CALIFORNIA OPERATIONS.
STATISTICS FOR 5000 DAYS WITH 3 ROUND TRIPS PER DAY, TOTALING 38041.3 FLIGHT HOURS.

	Number of Samples	Mean	Standard Deviation	Maximum Value	Minimum Value	Constraint Maximum	Number Greater	Constraint Minimum	Number Less
Equipment Repair Time (min)	1644	52.6	64.3	416.4	4.1	30.0	854	10.0	135
Fuel Loading Time (min)	31259	10.4	3.1	15.0	5.1	10.0	16969	5.0	0
Equipment Repair Delay (min)	1039	30.9	28.3	126.2	.0	30.0	404	10.0	274
Fuel Loading Delay (min)	5	1.1	.6	1.6	.3				
Cargo Loading Delay (min)	232	.7	.7	5.1	.0	5.0	1	1.0	178
Passenger Loading Delay (min)	2983	2.2	2.0	13.4	.0	5.0	287	1.0	1014
Fuel Loaded (lb)	31259	10749.6	6279.6	20000.0	100.4				
Initial Fuel Load (lb)	71352	17246.4	3104.3	20000.0	5764.3				
Initial Takeoff Weight (lb)	71352	94512.3	3104.3	97265.9	83030.2				
Gate Departure Delay (min)	20774	20.1	30.6	255.8	1.0	15.0	6194	5.0	8842
Takeoff Hold Time (min)	45786	2.0	2.0	24.5	.4	10.0	339	5.0	41870
Takeoff Delay (min)	71120	5.8	19.0	236.5	-2.2	10.0	8315	0.0	35590
Weather Delay on Takeoff (min)	972	44.7	33.2	119.8	- .0	60.0	308	1.0	17
Weather Delay Landing (min)	238	47.8	37.0	158.9	.4	60.0	75	1.0	6
Landing Hold Time (min)	45394	2.0	1.9	24.0	.4	10.0	310	5.0	41650
Total Flight Time (min)	71052	32.1	20.5	173.0	9.8				
Landing Time Delay (min)	71052	8.2	19.5	259.8	-7.6	30.0	4744	5.0	46531
Gate Arrival Delay (min)	71052	8.5	19.5	259.8	-7.4	15.0	7413	1.0	17592
Fuel Consumed (lb)	71052	3519.7	2211.3	15730.4	1212.7				
Fuel Remaining (lb)	71052	13717.8	4340.2	18768.2	3622.8				

Event	Occurrences	Event	Occurrences	Hardware Item	Failed	Repaired
Hardware Failure	2069	VFR Weather at Takeoff	66223	Flight Director System	14	0
Hardware Items Repaired	1667	Cat I Weather at Takeoff	4755	Flight Control(Pitch/Roll/Yaw)	60	0
Cancelled Due to Long Repair	118	Cat II Weather at Takeoff	71	Speed Control System	6	0
Gate Departure	71120	Cat III Weather at Takeoff	303	Primary Compass System	60	58
Dispatch Within 15 Minutes	64926	VFR Weather on Approach	66247	Backup Compass System	17	16
Scheduled Flight Time Exceeded	53346	Cat I Weather on Approach	4582	Attitude Reference	60	53
Divert to Alternate Airport	68	Cat II Weather on Approach	75	Air Data Computer System	15	14
ILS Failure	76	Cat III Weather on Approach	216	Altimeter	26	19
Hold for Takeoff Clearance	45786	Cat III Takeoff Capability	0	Airspeed	4	4
Hold for Landing Clearance	45394	Cat II Takeoff Capability	0	Primary Communications	53	50
Low Fuel Priority Landing	0	Cat I Takeoff Capability	71120	VHF NAV Receiver	92	81
Alternate Takeoff Runway Used	7322	Cat III Landing Capability	0	Backup Radio NAV	62	0
Alternate Landing Runway Used	7392	Cat II Landing Capability	0	Marker Beacon Receiver	15	0
Cancelled Due to Weather	232	Cat I Landing Capability	71071	DME	156	139
				Radio Altimeter	5	0
				ATC Transponder	38	36
				Weather Radar	122	0
				Flight Recorders	47	42
				Flight Interphone	7	7
				Instrument Comparison/Warning	13	0
				Additional Avionics	46	39
				Air Conditioning	184	177
				Oxygen System	46	44
				Hydraulics System	19	18
				Electrical System	4	4
				Fuel System	11	9
				Engines	28	22
				Additional Mechanical Items	859	835

Number of Samples - this is the number of times that the variable took on a specific value. For example, equipment repair does not occur at every stop and delays do not occur on every flight.

Mean - mean value of the variable taken only over the samples for which the variable had a value.

Standard Deviation - self-explanatory.

Maximum Value - self-explanatory.

Minimum Value - self-explanatory.

Constraint Maximum - a number entered by the user.

Number Greater - the number of samples which exceeded the constraint maximum.

Constraint Minimum - A number entered by the user.

Number Less - the number of samples which were less than the constraint minimum.

Following are some interpretations that can be drawn from Table 5. Under the left column of events, 2,069 items of hardware failed, of which 1,667 were repaired or replaced during the days' operations. The variable equipment repair time, at the top of the table, shows that the repairs occurred at 1,644 stops implying that at a few stops (the difference between 1,644 and 1,667), more than one item of hardware was repaired. Of the 1,644 repair times, 1,039 caused a delay (number of samples in the third row). Gate departure delays (10th row) occurred on 20,774 departures. Of those, 6,194 exceeded 15 minutes and 8,842 were less than 5 minutes. Weather delay (13th and 14th rows) occurred 972 times at take-off and 238 times on approach for an average of about 45 minutes. The smaller number of landing delays is due to the fact that the aircraft does not take-off from an airport until the weather at the destination is Category I or better.

Under events, there were 118 cancellations due to long repair. A flight is cancelled if a delay for any cause other than a late arrival exceeds 2 hours. There were 71,120 gate departures for the 5,000 days. If there had been no cancellations this number would be 75,000 since there are 15 legs per day. The difference between 75,000 and 71,120 is greater than the number of cancellations because the remainder of the day is not considered when a cancellation or diversion occurs.

The 68 diversions to alternate airports occurred because a weather delay on approach exceeded the fuel reserve capability. A long delay due to traffic congestion can cause a low fuel priority warning, however, none occurred. The 232 cancellations due to weather were caused by holds on take-off greater than 2 hours.

Under hardware items, the differences between number failed and number repaired is due either to the fact that the item doesn't have to be repaired during the day or that some of the failures occurred on the last leg.

Table 6 shows a comparison of the results of the simulations with some of the Air California data. There is a good match in dispatch reliability. Dispatch reliability is the percentage of the time that gate departures are less than 15 minutes late. Thus, it is 100 percent minus the probability of a departure delay greater than 15 minutes, which is also shown in the table. The simulation shows significantly less delay under 15 minutes than the Air California data. This is because there was no category of "other" delays which was entered into the simulation. As shown in Table 3, this source of delay amounted to 8.69 percent of total departures. It is assummed that these "other" delays were generally short delays because of the good correspondence of the simulation for large delays and because of the pronounced effect that "other" delays would have if they were very long. For example, maintenance delay in Table 3 are only 1.48 percent of total departures which would seem at first to be relatively insignificant. However, a single maintenance delay can cause an aircraft to be late for several successive flights because there is insufficient buffer in the schedule for making up losses. But successive delays are attributed to late arrivals (29.4 percent) as a source of gate departure delays. This category of late arrivals could mostly be allocated to sources of delay such as maintenance and weather. If the category of "other" delays was predominantly longer than 15 minutes, then the late arrival category would have to be much larger. In addition, simulation results in the next section will show that weather and maintenance delays have almost no impact on the departure delays under 15 minutes.

The simulated weather delays and cancellations occurred significantly more often than the Air California data show. This leads one to question the validity of the weather data or the interpretation of that data. In early simulations, the data were even more widely separated.

TABLE 6. COMPARISON OF AIR CALIFORNIA DATA AND SIMULATION RESULTS

	Air California Data	Simulation
Dispatch Reliability	89.67	91.32
Departure Delays (%)		
1-5 min	17.1	12.39
5-15 min	15.25	8.04
> 15 min	10.33	8.68
Repair Delay (%)	1.48	1.46
Weather Delay - Takeoff (%)	0.78	1.36
Cancel for Long Repair	174	118
Cancel for Weather	20	232

Because of the large disparity between the simulation and Air California data and the hazards of drawing improper conclusions based on exaggerated adverse weather, the weather probabilities and correlation times were arbitrarily halved. The data in Tables 5 and 6 and in simulation data in the next section reflect these reduced probabilities. Even with the reduced adverse ceiling and visibility probabilities, the simulation appears to exaggerate the actual Air California experience. However, it should be noted that the Air California data represent a sample of only 2 years, whereas, the data from NOAA generally reflect more than 10 years' experience. A word of caution should also be applied to the interpretation of Air California data. Their ground rules for cancellation are not nearly as arbitrary as the 2-hour delay used in the simulation. They seek alternative solutions such as rerouting, later flights, spare aircraft, etc., before accepting a flight cancellation.

Some of the results reflect very low probabilities and thus the confidence in the Monte Carlo results could be suspect. Table 7 shows the confidence that can be obtained for 75,000 and 5,000 trials. As an example, for an answer of 1.00 percent with 75,000 trials, there is a 99 percent confidence that the answer lies in the region 1.0 ± .0093.

The addition of an "other" category of gate departure delays (as listed in the Air California data of Table 3), with a distribution ranging from 1 to 20 minutes, would accomplish a precise match between Air California data and simulation results. The weather differences described above would then provide the only significant difference in results. The addition of the "other" category could be useful to assure that absolute results are correct. However, this addition would not affect a comparative or sensitivity analysis since there would be no justification for varying that source of delay.

Additional computer simulation runs were made to demonstrate the effectiveness of the simulation tool for determining the impact of various operational or equipment modifications. These are described in the next section.

TABLE 7. MONTE CARLO CONFIDENCE VALUES

Monte Carlo Result	Accuracy: 75,000 Trials, 95% Confidence	75,000 Trials, 99% Confidence	5,000 Trials, 95% Confidence	5,000 Trials, 99% Confidence
.99	7.1×10^{-5}	9.3×10^{-5}	2.7×10^{-4}	3.6×10^{-4}
.95	3.4×10^{-4}	4.5×10^{-4}	1.3×10^{-3}	1.7×10^{-3}
.9	6.4×10^{-4}	8.5×10^{-4}	2.5×10^{-3}	3.3×10^{-3}
.8	1.1×10^{-3}	1.5×10^{-3}	4.4×10^{-3}	5.8×10^{-3}
.7	1.5×10^{-3}	2.0×10^{-3}	5.8×10^{-3}	7.7×10^{-3}
.6	1.7×10^{-3}	2.3×10^{-3}	6.7×10^{-3}	8.8×10^{-3}
.5	1.8×10^{-3}	2.4×10^{-3}	6.9×10^{-3}	9.1×10^{-3}
.4	1.7×10^{-3}	2.3×10^{-3}	6.7×10^{-3}	8.8×10^{-3}
.3	1.5×10^{-3}	2.0×10^{-3}	5.8×10^{-3}	7.7×10^{-3}
.2	1.1×10^{-3}	1.5×10^{-3}	4.4×10^{-3}	5.8×10^{-3}
.1	6.4×10^{-4}	8.5×10^{-4}	2.5×10^{-3}	3.3×10^{-3}
.05	3.4×10^{-4}	4.5×10^{-4}	1.3×10^{-3}	1.7×10^{-3}
.01	7.1×10^{-5}	9.3×10^{-5}	2.7×10^{-4}	3.6×10^{-4}

Example: Monte Carlo result is .6 for 75,000 trials, then one has a 95% confidence that the true answer is in the interval .6 $\pm$ .0017.

Additional Simulation Results

The effectiveness evaluation computer simulation program can be a valuable supporting tool for technology development only if:

(1) It provides a reasonable representation of the external influences which affect a commercial air carrier

(2) It is sensitive to changes in characteristics of the specific equipment or procedure being evaluated.

In the previous section, it was demonstrated that the simulation can provide a good representation of existing short-haul operations. The purpose of this section is to demonstrate that the program, in its present state, has the necessary sensitivity to address several types of problems. Several simulations were run with the following variations.

(1) The complement of avionics aboard the Air California 737's was augmented with sufficient additional equipment and redundancy to achieve a Category II and then a Category III approach/land capability. The possible advantages to be achieved with these capabilities are of interest to many airlines and was a specific area of interest to Air California.

(2) With a Category III capability, several repair strategies were utilized for those items of equipment required for the Category III approach.

(3) Runs were made, in which only true equipment failures were acted upon, to determine the impact of eliminating unverified removals, a major cause of maintenance expense.

(4) The schedule was modified in two ways to determine if there was a best way to reduce the total number of flights.

The results for these cases are described below.

Improved Weather Capability.-Tables 8 and 9 show the equipment which was hypothesized to achieve Category II and III capabilities, respectively. Note that the differences in Category I (Table 4), II, and III are primarily the redundancy requirements. For Category III, it was assumed that the aircraft can land in any ceiling and visibility conditions. Mean time between unscheduled removal (MTBUR) data for Category III were taken from one avionics manufacturer's guarantees to an aircraft manufacturer

TABLE 8. CATEGORY II EQUIPMENT REQUIREMENTS

	Qty	Req'd for Dispatch	Fix @ 1st Sep. Stn.	Cat I	Cat II
Flight Director	2			1	2
Flight Control	1				
Speed Control	1				1
Primary Compass	2	2			
Backup Compass	1		1		
Attitude Reference	3	2	3	1	2
Air Data Computer	1	2	1		1
Altimeter	2		2		1
Airspeed	2	2			1
VHF Comm. Receiver	2	2	2		1
VHF Nav. Receiver	2	1		1	2
Marker Beacon Receiver	1				
DME	2	1	2		
Radio Altimeter	-				1
ATC Transponder	2	1	2		1
Weather Radar	1		1		
Flight Recorders	1		1		
Flight Interphone	1	1			
Instrument Comp/Warn	1				1
Additional Avionics	2	1	2		
Air Conditioning	1	1			
Oxygen	1	1			
Hydraulics	2	2			2
Electrical System	2	2			2
Engines	2	2			2
Additional Mech. Items	2	2			

TABLE 9. CATEGORY III EQUIPMENT REQUIREMENTS

Item	Qty	Req'd for Dispatch	Fix @ 1st Rep. Stn.	Cat I	Cat II	Cat III
Flight Director	2				2	2
Flight Control	3			1	2	3
Speed Control	2				1	2
Primary Compass	2	2				2
Backup Compass	1		1			
Attitude Reference	3	2	3	1	2	3
Air Data Computer	2	2	2		1	2
Altimeter	2		2			
Airspeed	2	2			1	1
VHF Comm. Receiver	2	2			1	1
VHF Nav. Receiver	3	1	2	1	2	3
Marker Beacon Receiver	1					
DME	2					
Radio Altimeter	2	2			1	2
ATC Transponder	2	1	2		1	1
Weather Radar	1		1			
Flight Recorders	1		1			
Flight Interphone	1	1				
Instrument Comp/Warn	2				1	2
Additional Avionics	2					
Air Conditioning	1	1				
Oxygen	1	1				
Hydraulics	3	3				3
Electrical System	2	2				2
Engines	2	2				2
Additional Mech. Items	2	2				

for equipment utilizing current analog technology. These MTBUR's were significantly less than for Air California's Category I experience, primarily because of the increased autopilot complexity and the level of redundancy. MTBUR data for Category II changes were estimated based on judgements regarding the increased complexity requirements.

Table 10 summarizes the results for several simulations. Tables 11 to 16 are results for each simulation and are in the same sequence as the columns (from left to right) in Table 10. The data in the first column of Table 10 came from the Air California simulation data of Table 5. The category heading on each column refers to the level of aircraft approach and landing capability, not to the actual weather encountered. Each simulation utilized the same weather data. The repair option refers to the repair strategy for equipment not specified by the minimum equipment list, but required for adverse ceiling and visibility conditions. For example, under the Category III heading, repair when failed means that if a failure occurs which would preclude a Category III landing, the item is repaired at the first stop regardless of actual weather conditions. Repair at SNA means that the same failure would not be repaired until the aircraft reached Orange County and would always be repaired there. Repair at SNA when IFR ahead means that the failure would be repaired only at Orange County and then only if there was IFR weather at the present time at one of the flight stops before returning to Orange County. All of the columns, except the two noted, utilize MTBUR distributions to determine when equipment is replaced or repaired. Industry experience is that approximately 50 percent of removals are unverified (checked out all right). For the two columns marked MTBF (mean-time-between failure), all avionics equipment MTBUR's were doubled. This would represent a hypothetical case in which the unverified removals could be eliminated with perfect on-board test equipment.

Dispatch reliability improves with increased adverse weather capability. Delays under 15 minutes are generally unaffected by the changes. The number of equipment removals increases drastically (almost 25 percent) when Category III capability is added. This is particularly dramatic in light of the fact that avionics failures comprised only about 20 percent of the total failures in the Category I case and only avionics items were added to achieve a Category III capability. Elimination of unverified removals reduces the number of failures to Category I levels. Weather delays and cancellations are reduced as expected with increased capabilities.

Average fuel consumption was lowest in the Category I case. This was not expected and turned out to be due to the fact that the hydraulics system weight was increased by 2,000 lb for the Category II and III cases. This was an excessive weight addition, particularly for Category II, but

TABLE 10. RESULTS OF SEVERAL COMPUTER SIMULATIONS

	Cat I	Cat II	Cat III				
	Repair at SNA if IFR Ahead	Repair at SNA if IFR Ahead	Repair When Failed	Repair at SNA		Repair at SNA When IFR Ahead	
				MTBUR	MTBF	MTBUR	MTBF
Dispatch Reliability (%)	91.32	93.86	95.45	95.79	96.91	96.65	97.11
Departure Delays 1-5 min (%)	12.39	12.64	12.57	12.80	12.86	12.71	12.80
5-15 min (%)	8.04	7.85	7.73	7.72	7.45	7.58	7.36
>15 min (%)	8.68	6.14	4.55	4.21	3.09	3.35	2.89
Number of Items Failed	2069	2139	2528	2477	1834	2461	1867
Number of Daytime Repairs	1667	1428	2232	2150	1618	1536	1344
Repair Delay (%)	1.46	1.26	1.95	1.75	1.31	1.31	1.14
Weather Delay - Takeoff (%)	1.36	1.002	-	0.020	0.028	0.214	0.170
- Landing (%)	.334	0.205	0.0014	0.120	0.0054	0.0203	0.012
Mean Fuel Per Leg (lb)	3519.7	3533.5	3525.3	3526.3	3523.9	3527.0	3527.2
Cancel for Long Repair	118	124	149	133	122	125	141
Cancel for Weather	232	147	-	2	-	37	38
Divert to Alternate Airport	68	81	7	9	8	10	8

TABLE 11. RESULTS OF SIMULATION OF AIR CALIFORNIA OPERATIONS WITH CATEGORY II APPROACH CAPABILITY (CAT II EQUIPMENT REPAIRED ONLY AT SNA WHEN IFR WEATHER AHEAD).
STATISTICS FOR 5000 DAYS WITH 3 ROUND TRIPS PER DAY, TOTALING 38208.7 FLIGHT HOURS

	Number of Samples	Mean	Standard Deviation	Maximum Value	Minimum Value	Constraint Maximum	Number Greater	Constraint Minimum	Number Less
Equipment Repair Time (min)	1401	55.7	70.8	475.1	5.0	30.0	695	10.0	94
Fuel Loading Time (min)	29278	10.6	3.2	15.0	5.1	10.0	18902	5.0	0
Equipment Repair Delay (min)	904	30.6	27.7	127.5	.0	30.0	342	10.0	231
Fuel Loading Delay (min)	0	0.0	0.0	0.0	0.0				
Cargo Loading Delay (min)	211	.7	.6	3.5	.0	5.0	0	1.0	155
Passenger Loading Delay (min)	3034	2.2	2.0	14.4	.0	5.0	302	1.0	1025
Fuel Loaded (lb)	29278	11536.0	6380.4	20000.0	105.1				
Initial Fuel Load (lb)	71756	16955.8	3237.5	20000.0	8541.7				
Initial Takeoff Weight (lb)	71756	95987.7	3237.5	99031.9	87573.6				
Gate Departure Delay (min)	19116	15.4	25.0	265.7	1.0	15.0	4409	5.0	9072
Takeoff Hold Time (min)	45715	2.0	2.0	24.0	.4	10.0	339	5.0	41719
Takeoff Delay (min)	71609	4.1	14.7	265.4	-2.2	10.0	6434	0.0	37456
Weather Delay on Takeoff (min)	719	43.6	32.7	119.4	.1	60.0	221	1.0	14
Weather Delay Landing (min)	147	39.7	34.6	136.7	.3	60.0	39	1.0	4
Landing Hold Time (min)	45134	2.0	1.9	21.0	.4	10.0	284	5.0	41618
Total Flight Time (min)	71528	32.1	20.4	164.9	9.8				
Landing Time Delay (min)	71528	6.4	15.1	264.9	-8.6	30.0	3163	5.0	48431
Gate Arrival Delay (min)	71528	6.6	15.0	266.0	-8.1	15.0	5559	1.0	18280
Fuel Consumed (lb)	71528	3533.5	2220.6	15360.0	1218.4				
Fuel Remaining (lb)	71528	13424.3	4528.3	18762.6	3301.9				48431

Event	Occurrences	Event	Occurrences	Hardware Item	Failed	Repaired
Hardware Failure	2139	VFR Weather at Takeoff	66640	Flight Director System	11	2
Hardware Items Repaired	1428	Cat I Weather at Takeoff	4568	Flight Control (Pitch/Roll/Yaw)	126	41
Cancelled Due to Long Repair	124	Cat II Weather at Takeoff	270	Speed Control System	13	3
Gate Departure	71609	Cat III Weather at Takeoff	278	Primary Compass System	61	60
Dispatch Within 15 Minutes	67200	VFR Weather on Approach	66635	Backup Compass System	9	2
Scheduled Flight Time Exceeded	53839	Cat I Weather on Approach	4521	Attitude Reference	70	22
Divert to Alternate Airport	81	Cat II Weather on Approach	233	Air Data Computer System	19	11
ILS Failure	60	Cat III Weather on Approach	220	Altimeter	26	12
Hold for Takeoff Clearance	45715	Cat III Takeoff Capability	0	Airspeed	7	6
Hold for Landing Clearance	45134	Cat II Takeoff Capability	70134	Primary Communications	60	60
Low Fuel Priority Landing	0	Cat I Takeoff Capability	1475	VHF NAV Receiver	89	25
Alternate Takeoff Runway Used	7456	Cat III Landing Capability	0	Backup Radio NAV	50	0
Alternate Landing Runway Used	7472	Cat II Landing Capability	69824	Marker Beacon Receiver	25	0
Cancelled Due to Weather	147	Cat I Landing Capability	1754	DME	131	34
				Radio Altimeter	6	0
				ATC Transponder	47	12
				Weather Radar	109	0
				Flight Recorders	62	22
				Flight Interphone	10	10
				Instrument Comparison/Warning	22	4
				Additional Avionics	44	17
				Air Conditioning	170	161
				Oxygen System	51	50
				Hydraulics System	39	16
				Electrical System	10	9
				Fuel System	11	11
				Engines	23	22
				Additional Mechanical Items	837	815

TABLE 12. RESULTS OF SIMULATING OF AIR CALIFORNIA OPERATIONS WITH CATEGORY III APPROACH/LAND CAPABILITY (REPAIR TO CAT III AT ALL STOPS). STATISTICS FOR 5000 DAYS WITH 3 ROUND TRIPS PER DAY, TOTALING 39280.4 FLIGHT HOURS

	Number of Samples	Mean	Standard Deviation	Maximum Value	Minimum Value	Constraint Maximum	Number Greater	Constraint Minimum	Number Less
Equipment Repair Time (min)	2206	51.2	58.3	398.4	4.2	30.0	1179	10.0	172
Fuel Loading Time (min)	29608	10.8	3.2	15.0	5.1	10.0	19740	5.0	0
Equipment Repair Delay (min)	1443	32.7	28.0	124.1	.0	30.0	607	10.0	337
Fuel Loading Delay (min)	0	0.0	0.0	0.0	0.0				
Cargo Loading Delay (min)	210	.7	.6	3.5	.0	5.0	0	1.0	155
Passenger Loading Delay (min)	3125	2.2	2.0	13.0	.0	5.0	295	1.0	1087
Fuel Loaded (lb)	29608	11669.6	6366.4	20000.0	102.2				
Initial Fuel Load (lb)	73829	16908.2	3254.4	20000.0	10904.1				
Initial Takeoff Weight (lb)	73829	96207.8	3254.4	99299.6	90203.7				
Gate Departure Delay (min)	18346	12.2	20.0	214.3	1.0	15.0	3357	5.0	9282
Takeoff Hold Time (min)	46427	2.0	2.0	27.9	.4	10.0	390	5.0	42328
Takeoff Delay (min)	73829	3.0	11.5	213.2	-2.2	10.0	5456	0.0	39636
Weather Delay on Takeoff (min)	0	0.0	0.0	0.0	0.0	60.0	0	1.0	0
Weather Delay Landing (min)	1	151.7	0.0	151.7	151.7	60.0	1	1.0	0
Landing Hold Time (min)	45916	2.0	1.9	22.7	.4	10.0	289	5.0	42210
Total Flight Time (min)	73822	31.9	20.3	161.5	9.8				
Landing Time Delay (min)	73822	5.2	11.7	214.8	-8.7	30.0	2215	5.0	51147
Gate Arrival Delay (min)	73822	5.5	11.7	214.2	-8.1	15.0	4477	1.0	19791
Fuel Consumed (lb)	73822	3525.3	2215.9	13863.0	1219.4				
Fuel Remaining (lb)	73822	13383.2	4560.5	18762.0	3185.6				

Event	Occurrences
Hardware Failure	2528
Hardware Items Repaired	2232
Cancelled Due to Long Repair	149
Gate Departure	73829
Dispatch Within 15 Minutes	70472
Scheduled Flight Time Exceeded	55355
Divert to Alternate Airport	7
ILS Failure	71
Hold for Takeoff Clearance	46427
Hold for Landing Clearance	45916
Low Fuel Priority Landing	0
Alternate Takeoff Runway Used	7770
Alternate Landing Runway Used	7756
Cancelled Due to Weather	0

Event	Occurrences
VFR Weather at Takeoff	68080
Cat I Weather at Takeoff	4714
Cat II Weather at Takeoff	251
Cat III Weather at Takeoff	784
VFR Weather on Approach	68222
Cat I Weather on Approach	4673
Cat II Weather on Approach	261
Cat III Weather on Approach	673
Cat III Takeoff Capability	73829
Cat II Takeoff Capability	0
Cat I Takeoff Capability	0
Cat III Landing Capability	73063
Cat II Landing Capability	677
Cat I Landing Capability	49

Hardware Item	Failed	Repaired
Flight Director System	12	11
Flight Control (Pitch/Roll/Yaw)	276	266
Speed Control System	45	43
Primary Compass System	67	67
Backup Compass System	20	18
Attitude Reference	56	55
Air Data Computer System	19	16
Altimeter	24	23
Airspeed	5	5
Primary Communications	74	68
VHF NAV Receiver	152	145
Backup Radio NAV	56	0
Marker Beacon Receiver	12	0
DME	156	135
Radio Altimeter	88	85
ATC Transponder	37	33
Weather Radar	126	0
Flight Recorders	63	57
Flight Interphone	8	8
Instrument Comparison/Warning	31	30
Additional Avionics	33	33
Air Conditioning	196	192
Oxygen System	56	55
Hydraulics System	43	43
Electrical System	7	7
Fuel System	6	6
Engines	35	31
Additional Mechanical Items	825	800

TABLE 13. RESULTS OF SIMULATION OF AIR CALIFORNIA OPERATIONS WITH CATEGORY III APPROACH/LAND CAPABILITY (REPAIR TO CAT III AT SNA).
STATISTICS FOR 5000 DAYS WITH 3 ROUND TRIPS PER DAY, TOTALING 39334.2 FLIGHT HOURS

	Number of Samples	Mean	Standard Deviation	Maximum Value	Minimum Value	Constraint Maximum	Number Greater	Constraint Minimum	Number Less
Equipment Repair Time (min)	2109	51.9	59.4	398.4	4.1	30.0	1132	10.0	168
Fuel Loading Time (min)	29611	10.8	3.2	15.0	5.1	10.0	19743	5.0	0
Equipment Repair Delay (min)	1290	30.6	27.5	126.8	.0	30.0	494	10.0	327
Fuel Loading Delay (min)	0	0.0	0.0	0.0	0.0				
Cargo Loading Delay (min)	225	.7	.6	3.5	.0	5.0	0	1.0	176
Passenger Loading Delay (min)	3111	2.3	2.0	13.0	.0	5.0	319	1.0	1036
Fuel Loaded (lb)	29611	11671.9	6363.9	20000.0	108.6				
Initial Fuel Load (lb)	73891	16905.9	3255.4	20000.0	10903.7				
Initial Takeoff Weight (lb)	73891	96205.5	3255.4	99299.6	90203.3				
Gate Departure Delay (min)	18272	11.8	19.8	211.6	1.0	15.0	3110	5.0	9458
Takeoff Hold Time (min)	46618	2.0	2.0	24.0	.4	10.0	346	5.0	42684
Takeoff Delay (min)	73889	2.8	11.3	210.0	-2.2	10.0	5189	0.0	39968
Weather Delay on Takeoff (min)	15	58.7	33.9	108.4	12.6	60.0	6	1.0	0
Weather Delay Landing (min)	9	66.0	43.9	135.3	12.4	60.0	5	1.0	0
Landing Hold Time (min)	46124	2.0	1.9	23.6	.4	10.0	312	5.0	42429
Total Flight Time (min)	73880	31.9	20.3	145.0	9.8				
Landing Time Delay (min)	73880	5.1	11.6	207.6	-8.2	30.0	2032	5.0	51526
Gate Arrival Delay (min)	73880	5.4	11.6	207.4	-7.7	15.0	4278	1.0	19915
Fuel Consumed (lb)	73880	3526.3	2216.2	12493.1	1219.4				
Fuel Remaining (lb)	73880	13379.9	4561.8	18761.9	3185.6				

Event	Occurrences
Hardware Failure	2477
Hardware Items Repaired	2150
Cancelled Due to Long Repair	133
Gate Departure	73889
Dispatch Within 15 Minutes	70779
Scheduled Flight Time Exceeded	55428
Divert to Alternate Airport	9
ILS Failure	68
Hold for Takeoff Clearance	46618
Hold for Landing Clearance	46124
Low Fuel Priority Landing	0
Alternate Takeoff Runway Used	7736
Alternate Landing Runway Used	7723
Cancelled Due to Weather	2

Event	Occurrences
VFR Weather at Takeoff	68086
Cat I Weather at Takeoff	4767
Cat II Weather at Takeoff	262
Cat III Weather at Takeoff	776
VFR Weather on Approach	68219
Cat I Weather on Approach	4730
Cat II Weather on Approach	263
Cat III Weather on Approach	677
Cat III Takeoff Capability	73253
Cat II Takeoff Capability	600
Cat I Takeoff Capability	36
Cat III Landing Capability	72507
Cat II Landing Capability	1269
Cat I Landing Capability	75

Hardware Item	Failed	Repaired
Flight Director System	10	8
Flight Control (Pitch/Roll/Yaw)	268	230
Speed Control System	42	37
Primary Compass System	66	64
Backup Compass System	20	19
Attitude Reference	67	62
Air Data Computer System	24	19
Altimeter	25	24
Airspeed	7	7
Primary Communications	74	72
VHF NAV Receiver	155	138
Backup Radio NAV	45	0
Marker Beacon Receiver	18	0
DME	141	124
Radio Altimeter	81	75
ATC Transponder	38	35
Weather Radar	119	0
Flight Recorders	71	64
Flight Interphone	4	3
Instrument Comparison/Warning	31	29
Additional Avionics	45	42
Air Conditioning	180	176
Oxygen System	52	51
Hydraulics System	33	31
Electrical System	6	6
Fuel System	6	6
Engines	33	29
Additional Mechanical Items	813	796

TABLE 14. RESULTS OF SIMULATION OF AIR CALIFORNIA OPERATIONS WITH CATEGORY III APPROACH/LAND CAPABILITY (REPAIR TO CAT III AT SNA. AVIONICS MTBUR's DOUBLED).
STATISTICS FOR 5000 DAYS WITH 3 ROUND TRIPS PER DAY, TOTALING 39394.0 FLIGHT HOURS

	Number of Samples	Mean	Standard Deviation	Maximum Value	Minimum Value	Constraint Maximum	Number Greater	Constraint Minimum	Number Less
Equipment Repair Time (min)	1601	52.4	65.6	477.5	5.0	30.0	799	10.0	132
Fuel Loading Time (min)	29734	10.8	3.2	15.0	5.1	10.0	19728	5.0	0
Equipment Repair Delay (min)	973	29.9	27.7	124.9	.0	30.0	335	10.0	240
Fuel Loading Delay (min)	0	0.0	0.0	0.0	0.0				
Cargo Loading Delay (min)	232	.6	.6	3.5	.0	5.0	0	1.0	188
Passenger Loading Delay (min)	3162	2.2	2.0	13.0	.0	5.0	325	1.0	1047
Fuel Loaded (lb)	29734	11641.5	6363.9	20000.0	103.6				
Initial Fuel Load (lb)	74065	16915.6	3251.9	20000.0	10903.1				
Initial Takeoff Weight (lb)	74065	96215.2	3251.9	99299.6	90202.7				
Gate Departure Delay (min)	17331	9.7	16.2	154.6	1.0	15.0	2291	5.0	9524
Takeoff Hold Time (min)	46632	2.0	2.0	27.0	.4	10.0	323	5.0	42624
Takeoff Delay (min)	74065	2.2	9.1	158.3	-2.2	10.0	4198	0.0	40640
Weather Delay on Takeoff (min)	21	43.9	27.4	82.9	.2	60.0	7	1.0	2
Weather Delay Landing (min)	4	78.0	37.6	117.5	27.0	60.0	3	1.0	0
Landing Hold Time (min)	46078	1.9	1.9	22.7	.4	10.0	287	5.0	42494
Total Flight Time (min)	74057	31.9	20.3	127.3	9.8				
Landing Time Delay (min)	74057	4.4	9.5	161.8	-8.7	30.0	1408	5.0	52491
Gate Arrival Delay (min)	74057	4.7	9.4	162.5	-8.1	15.0	3325	1.0	20404
Fuel Consumed (lb)	74057	3523.9	2215.1	11050.4	1219.3				
Fuel Remaining (lb)	74057	13391.7	4557.0	18761.9	3185.6				

Event	Occurrences	Event	Occurrences	Hardware Item	Failed	Repaired
Hardware Failure	1834	VFR Weather at Takeoff	68203	Flight Director System	4	4
Hardware Items Repaired	1618	Cat I Weather at Takeoff	4825	Flight Control(Pitch/Roll/Yaw)	129	112
Cancelled Due to Long Repair	122	Cat II Weather at Takeoff	259	Speed Control System	27	20
Gate Departure	74065	Cat III Weather at Takeoff	778	Primary Compass System	29	26
Dispatch Within 15 Minutes	71774	VFR Weather on Approach	68351	Backup Compass System	11	10
Scheduled Flight Time Exceeded	55506	Cat I Weather on Approach	4763	Attitude Reference	29	25
Divert to Alternate Airport	8	Cat II Weather on Approach	282	Air Data Computer System	11	9
ILS Failure	63	Cat III Weather on Approach	669	Altimeter	10	10
Hold for Takeoff Clearance	46632	Cat III Takeoff Capability	73741	Airspeed	2	2
Hold for Landing Clearance	46078	Cat II Takeoff Capability	298	Primary Communications	25	25
Low Fuel Priority Landing	0	Cat I Takeoff Capability	26	VHF NAV Receiver	73	61
Alternate Takeoff Runway Used	7787	Cat III Landing Capability	73370	Backup Radio NAV	31	0
Alternate Landing Runway Used	7838	Cat II Landing Capability	619	Marker Beacon Receiver	15	0
Cancelled Due to Weather	0	Cat I Landing Capability	58	DME	65	60
				Radio Altimeter	44	40
				ATC Transponder	18	16
				Weather Radar	52	0
				Flight Recorders	38	32
				Flight Interphone	1	1
				Instrument Comparison/Warning	13	11
				Additional Avionics	47	43
				Air Conditioning	194	183
				Oxygen System	62	59
				Hydraulics System	29	26
				Electrical System	8	8
				Fuel System	5	5
				Engines	14	10
				Additional Mechanical Items	846	818

TABLE 15. RESULTS OF SIMULATION OF AIR CALIFORNIA OPERATIONS WITH CATEGORY III APPROACH/LAND CAPABILITY (REPAIR TO CAT III AT SNA ONLY WHEN IFR AHEAD). STATISTICS FOR 5000 DAYS WITH 3 ROUND TRIPS PER DAY, TOTALING 39236.4 FLIGHT HOURS

	Number of Samples	Mean	Standard Deviation	Maximum Value	Minimum Value	Constraint Maximum	Number Greater	Constraint Minimum	Number Less
Equipment Repair Time (min)	1503	54.5	69.2	397.9	4.0	30.0	766	10.0	107
Fuel Loading Time (min)	30017	10.7	3.2	15.0	5.1	10.0	19301	5.0	0
Equipment Repair Delay (min)	966	28.8	26.2	126.8	.0	30.0	349	10.0	271
Fuel Loading Delay (min)	0	0.0	0.0	0.0	0.0				
Cargo Loading Delay (min)	222	.7	.7	3.5	.0	5.0	0	1.0	170
Passenger Loading Delay (min)	3133	2.2	2.0	13.0	.0	5.0	305	1.0	1055
Fuel Loaded (lb)	30017	11497.3	6365.0	20000.0	103.6				
Initial Fuel Load (lb)	73735	16960.1	3236.4	20000.0	10903.7				
Initial Takeoff Weight (lb)	73735	96259.7	3236.4	99299.6	90203.3				
Gate Departure Delay (min)	17428	10.6	18.8	313.3	1.0	15.0	2467	5.0	9371
Takeoff Hold Time (min)	46424	2.0	2.0	21.9	.4	10.0	376	5.0	42407
Takeoff Delay (min)	73698	2.4	10.5	313.1	-2.2	10.0	4472	0.0	40294
Weather Delay on Takeoff (min)	158	45.7	31.5	119.8	.1	60.0	51	1.0	3
Weather Delay Landing (min)	15	52.2	25.7	91.1	11.0	60.0	6	1.0	0
Landing Hold Time (min)	45876	2.0	1.9	23.0	.4	10.0	302	5.0	42163
Total Flight Time (min)	73688	31.9	20.3	139.3	9.8				
Landing Time Delay (min)	73688	4.7	10.8	313.2	-8.2	30.0	1591	5.0	51985
Gate Arrival Delay (min)	73688	4.9	10.7	313.9	-7.7	15.0	3576	1.0	20036
Fuel Consumed (lb)	73688	3527.0	2216.0	13120.2	1219.4				
Fuel Remaining (lb)	73688	13432.6	4530.9	18762.0	3326.4				

Event	Occurrences	Event	Occurrences	Hardware Item	Failed	Repaired
Hardware Failure	2461	VFR Weather at Takeoff	67925	Flight Director System	12	3
Hardware Items Repaired	1536	Cat I Weather at Takeoff	4811	Flight Control(Pitch/Roll/Yaw)	266	80
Cancelled Due to Long Repair	125	Cat II Weather at Takeoff	241	Speed Control System	47	12
Gate Departure	73698	Cat III Weather at Takeoff	758	Primary Compass System	59	56
Dispatch Within 15 Minutes	71231	VFR Weather on Approach	68041	Backup Compass System	19	7
Scheduled Flight Time Exceeded	55266	Cat I Weather on Approach	4816	Attitude Reference	64	21
Divert to Alternate Airport	10	Cat II Weather on Approach	226	Air Data Computer System	23	8
ILS Failure	71	Cat III Weather on Approach	615	Altimeter	25	10
Hold for Takeoff Clearance	46424	Cat III Takeoff Capability	70240	Airspeed	12	12
Hold for Landing Clearance	45876	Cat II Takeoff Capability	3224	Primary Communications	68	64
Low Fuel Priority Landing	0	Cat I Takeoff Capability	234	VHF NAV Receiver	147	45
Alternate Takeoff Runway Used	7649	Cat III Landing Capability	69526	Backup Radio NAV	50	0
Alternate Landing Runway Used	7631	Cat II Landing Capability	3856	Marker Beacon Receiver	12	0
Cancelled Due to Weather	37	Cat I Landing Capability	281	DME	137	47
				Radio Altimeter	89	33
				ATC Transponder	31	10
				Weather Radar	126	0
				Flight Recorders	70	20
				Flight Interphone	8	7
				Instrument Comparison/Warning	33	12
				Additional Avionics	34	13
				Air Conditioning	181	179
				Oxygen System	45	44
				Hydraulics System	35	15
				Electrical System	7	7
				Fuel System	7	7
				Engines	30	26
				Additional Mechanical Items	821	795

TABLE 16. RESULTS OF SIMULATION OF AIR CALIFORNIA OPERATIONS WITH CATEGORY III APPROACH/LAND CAPABILITY (REPAIR TO CAT III AT SNA ONLY WHEN IFR AHEAD. AVIONICS MTBUR's DOUBLED).
STATISTICS FOR 5000 DAYS WITH 3 ROUND TRIPS PER DAY, TOTALING 39181.4 FLIGHT HOURS

	Number of Samples	Mean	Standard Deviation	Maximum Value	Minimum Value	Constraint Maximum	Number Greater	Constraint Minimum	Number Less
Equipment Repair Time (min)	1315	59.6	76.5	463.3	5.0	30.0	682	10.0	78
Fuel Loading Time (min)	29892	10.8	3.2	13.0	5.1	10.0	19350	5.0	0
Equipment Repair Delay (min)	841	30.3	27.3	124.6	.0	30.0	313	10.0	205
Fuel Loading Delay (min)	0	0.0	0.0	0.0	0.0				
Cargo Loading Delay (min)	226	.7	.6	3.5	.0	5.0	0	1.0	172
Passenger Loading Delay (min)	3027	2.2	2.0	13.3	.0	5.0	288	1.0	1023
Fuel Loaded (lb)	29892	11531.5	6366.7	20000.0	102.2				
Initial Fuel Load (lb)	73633	16949.8	3239.7	20000.0	10904.1				
Initial Takeoff Weight (lb)	73633	96249.4	3239.7	99299.6	90203.7				
Gate Departure Delay (min)	16972	9.7	17.3	198.0	1.0	15.0	2127	5.0	9426
Takeoff Hold Time (min)	46556	2.0	2.0	21.9	.4	10.0	337	5.0	42455
Takeoff Delay (min)	73595	2.2	9.6	199.6	-2.2	10.0	4064	0.0	40533
Weather Delay on Takeoff (min)	125	44.1	32.7	119.5	.4	60.0	35	1.0	2
Weather Delay Landing (min)	9	61.8	41.4	152.3	20.6	60.0	3	1.0	0
Landing Hold Time (min)	45896	2.0	1.9	22.7	.4	10.0	285	5.0	42260
Total Flight Time (min)	73587	31.9	20.3	173.5	9.8				
Landing Time Delay (min)	73587	4.5	9.9	202.8	-8.2	30.0	1349	5.0	52289
Gate Arrival Delay (min)	73587	4.7	9.9	202.8	-7.7	15.0	3197	1.0	20193
Fuel Consumed (lb)	73587	3527.2	2216.5	14860.0	1219.3				
Fuel Remaining (lb)	73587	13422.1	4536.4	18762.0	3497.9				

Event	Occurrences
Hardware Failure	1867
Hardware Items Repaired	1344
Cancelled Due to Long Repair	141
Gate Departure	73595
Dispatch Within 15 Minutes	71468
Scheduled Flight Time Exceeded	55274
Divert to Alternate Airport	8
ILS Failure	67
Hold for Takeoff Clearance	46556
Hold for Landing Clearance	45896
Low Fuel Priority Landing	0
Alternate Takeoff Runway Used	7685
Alternate Landing Runway Used	7726
Cancelled Due to Weather	38

Event	Occurrences
VFR Weather at Takeoff	67883
Cat I Weather at Takeoff	4746
Cat II Weather at Takeoff	248
Cat III Weather at Takeoff	756
VFR Weather on Approach	67995
Cat I Weather on Approach	4726
Cat II Weather on Approach	246
Cat III Weather on Approach	628
Cat III Takeoff Capability	71765
Cat II Takeoff Capability	1650
Cat I Takeoff Capability	180
Cat III Landing Capability	71352
Cat II Landing Capability	1996
Cat I Landing Capability	216

Hardware Item	Failed	Repaired
Flight Director System	6	1
Flight Control (Pitch/Roll/Yaw)	143	50
Speed Control System	21	10
Primary Compass System	28	28
Backup Compass System	8	3
Attitude Reference	34	7
Air Data Computer System	10	4
Altimeter	13	5
Airspeed	4	4
Primary Communications	36	35
VHF NAV Receiver	62	25
Backup Radio NAV	27	0
Marker Beacon Receiver	8	0
DME	57	15
Radio Altimeter	55	23
ATC Transponder	21	10
Weather Radar	52	0
Flight Recorders	29	6
Flight Interphone	6	6
Instrument Comparison/Warning	20	4
Additional Avionics	46	14
Air Conditioning	188	181
Oxygen System	63	59
Hydraulics System	33	15
Electrical System	8	7
Fuel System	7	6
Engines	22	20
Additional Mechanical Items	838	804

does serve to show how increased weight can affect fuel savings gained by not having to hold in-flight for weather. It should also be noted that in-flight holding was minimized under Category I and II conditions by holding on the ground until weather minimums at the next airport were acceptable. Holding for weather occurred then only if the conditions changed en route.

In the simulation, it was assumed that if a given weather category existed and the aircraft was capable of accommodating that condition, then a landing occurred on the first attempt. However, there is evidence that under Category II conditions, a significant number of go-arounds occur. This is probably due to rapidly changing conditions and to a pilot's inclination to be sure of a good landing before proceeding. It would be expected that under Category IIIb conditions, where a pilot would not be required to obtain a runway visual contact, that the number of these go-arounds would be significantly reduced. Thus, the improvements in performance for Category II are very likely not as great, in reality, as shown in Table 10.

It can be concluded from Table 10 that increased adverse weather landing and take-off capabilities improve scheduled performance. This improvement, however, can be largely offset by increased maintenance costs if some means is not found to improve the maintenance requirements for the more complex avionics equipment.

Schedule Changes.-The recent airline schedule cutbacks due to fuel shortages have led to a strong emphasis on methods of optimizing limited flight schedules. Two computer runs were made to determine what all would change in response to schedule changes. In both cases, the three last flight legs (20 percent of the flights) were eliminated. Then, in one case (Table 17), the block time for each flight leg was increased by 5 minutes. This increased the flight day by 1 hour. In the second case (Table 18) all gate stops less than 20 minutes were increased to 20 minutes. This increased the flight day by 65 minutes. Table 19 summarizes pertinent data from the two cases. About the only real conclusion that can be drawn is that schedule reliability is slightly better when the minimum gate time is restricted to 20 minutes. Other differences are so small that they can very likely be attributed to Monte Carlo variations.

TABLE 17. RESULTS OF SIMULATION OF AIR CALIFORNIA OPERATIONS (THREE FLIGHT LEGS DELETED AND ALL BLOCK TIMES INCREASED BY 5 MINUTES). STATISTICS FOR 5000 DAYS WITH 3 ROUND TRIPS PER DAY, TOTALING 31822.0 FLIGHT HOURS

	Number of Samples	Mean	Standard Deviation	Maximum Value	Minimum Value	Constraint Maximum	Number Greater	Constraint Minimum	Number Less
Equipment Repair Time (min)	1372	50.5	64.2	476.3	4.4	30.0	680	10.0	115
Fuel Loading Time (min)	26410	10.2	3.3	15.0	5.1	10.0	13074	5.0	0
Equipment Repair Delay (min)	851	29.0	27.1	122.8	.0	30.0	300	10.0	241
Fuel Loading Delay (min)	1	.3	0.0	.3	.3				
Cargo Loading Delay (min)	114	.6	.5	2.4	.0	5.0	0	1.0	89
Passenger Loading Delay (min)	2252	2.2	2.0	16.1	.0	5.0	209	1.0	798
Fuel Loaded (lb)	26410	10317.9	6640.6	20000.0	101.9				
Initial Fuel Load (lb)	58125	17261.5	3053.3	20000.0	5764.3				
Initial Takeoff Weight (lb)	58125	94527.4	3053.3	97265.9	83030.2				
Gate Departure Delay (min)	7739	21.9	29.7	261.8	1.0	15.0	2941	5.0	3097
Takeoff Hold Time (min)	39670	2.2	2.1	30.0	.4	10.0	403	5.0	35757
Takeoff Delay (min)	57985	3.0	13.3	261.0	-2.2	10.0	3816	0.0	33050
Weather Delay on Takeoff (min)	632	43.1	31.9	119.0	.0	60.0	182	1.0	11
Weather Delay Landing (min)	157	47.0	38.0	158.7	.3	60.0	46	1.0	2
Landing Hold Time (min)	37000	2.1	2.0	21.9	.4	10.0	299	5.0	33581
Total Flight Time (min)	57947	32.9	19.7	180.2	9.8				
Landing Time Delay (min)	57947	.4	13.9	253.2	-12.4	30.0	1893	5.0	51898
Gate Arrival Delay (min)	57947	.6	13.9	253.9	-11.8	15.0	2895	1.0	44025
Fuel Consumed (lb)	57947	3603.7	2133.0	15697.8	1212.9				
Fuel Remaining (lb)	57947	13651.4	3975.8	18767.9	3610.4				

Event	Occurrences	Event	Occurrences	Hardware Item	Failed	Repaired
Hardware Failure	1761	VFR Weather at Takeoff	54164	Flight Director System	4	0
Hardware Items Repaired	1389	Cat I Weather at Takeoff	3774	Flight Control (Pitch/Roll/Yaw)	56	0
Cancelled Due to Long Repair	90	Cat II Weather at Takeoff	45	Speed Control System	14	0
Gate Departure	57985	Cat III Weather at Takeoff	142	Primary Compass System	52	50
Dispatch Within 15 Minutes	55044	VFR Weather on Approach	54084	Backup Compass System	13	11
Scheduled Flight Time Exceeded	8352	Cat I Weather on Approach	3715	Attitude Reference	57	46
Divert to Alternate Airport	38	Cat II Weather on Approach	45	Air Data Computer System	13	11
ILS Failure	58	Cat III Weather on Approach	141	Altimeter	20	17
Hold for Takeoff Clearance	39670	Cat III Takeoff Capability	0	Airspeed	7	7
Hold for Landing Clearance	37000	Cat II Takeoff Capability	0	Primary Communications	41	40
Low Fuel Priority Landing	0	Cat I Takeoff Capability	57985	VHF NAV Receiver	84	71
Alternate Takeoff Runway Used	6636	Cat III Landing Capability	0	Backup Radio NAV	54	0
Alternate Landing Runway Used	6598	Cat II Landing Capability	0	Marker Beacon Receiver	8	0
Cancelled Due to Weather	140	Cat I Landing Capability	57939	DME	132	109
				Radio Altimeter	6	0
				ATC Transponder	34	30
				Weather Radar	87	0
				Flight Recorders	47	39
				Flight Interphone	5	5
				Instrument Comparison/Warning	11	0
				Additional Avionics	50	41
				Air Conditioning	164	155
				Oxygen System	39	35
				Hydraulics System	21	20
				Electrical System	7	6
				Fuel System	10	9
				Engines	21	19
				Additional Mechanical Items	703	667

TABLE 18. RESULTS OF SIMULATION OF AIR CALIFORNIA OPERATIONS (THREE FLIGHT LEGS DELETED AND ALL GATE TIME LESS THAN 20 MINUTES INCREASED TO 20 MINUTES). STATISTICS FOR 5000 DAYS WITH 3 ROUND TRIPS PER DAY, TOTALING 31757.7 FLIGHT HOURS.

	Number of Samples	Mean	Standard Deviation	Maximum Value	Minimum Value	Constraint Maximum	Number Greater	Constraint Minimum	Number Less
Equipment Repair Time (min)	1373	50.4	59.9	397.3	4.3	30.0	693	10.0	138
Fuel Loading Time (min)	26421	10.2	3.3	15.0	5.1	10.0	13016	5.0	0
Equipment Repair Delay (min)	745	31.1	28.8	123.6	.0	30.0	281	10.0	196
Fuel Loading Delay (min)	0	0.0	0.0	0.0	0.0				
Cargo Loading Delay (min)	0	0.0	0.0	0.0	0.0	5.0	0	1.0	0
Passenger Loading Delay (min)	662	1.9	1.8	13.2	.0	5.0	40	1.0	252
Fuel Loaded (lb)	26421	10302.8	6636.0	20000.0	100.0				
Initial Fuel Load (lb)	58015	17267.5	3051.7	20000.0	6868.1				
Initial Takeoff Weight (lb)	58015	94533.4	3051.7	97265.9	84134.0				
Gate Departure Delay (min)	5356	29.3	31.6	251.8	1.0	15.0	2856	5.0	1453
Takeoff Hold Time (min)	39419	2.2	2.2	26.0	.4	10.0	430	5.0	35386
Takeoff Delay (min)	57867	2.8	13.0	251.0	-2.2	10.0	3523	0.0	33966
Weather Delay on Takeoff (min)	660	41.2	30.9	119.6	.1	60.0	177	1.0	8
Weather Delay Landing (min)	154	46.7	38.7	160.7	.2	60.0	36	1.0	1
Landing Hold Time (min)	36939	2.1	2.0	22.7	.4	10.0	319	5.0	33538
Total Flight Time (min)	57834	32.9	19.7	177.8	9.8				
Landing Time Delay (min)	57834	5.2	13.6	248.2	-7.1	30.0	2160	5.0	42125
Gate Arrival Delay (min)	57834	5.4	13.6	248.9	-6.7	15.0	3507	1.0	19432
Fuel Consumed (lb)	57834	3604.3	2131.7	15380.2	1212.8				
Fuel Remaining (lb)	57834	13656.9	3971.8	18768.3	3609.1				

Event	Occurrences	Event	Occurrences	Hardware Item	Failed	Repaired
Hardware Failure	1810	VFR Weather at Takeoff	53912	Flight Director System	8	0
Hardware Items Repaired	1393	Cat I Weather at Takeoff	3890	Flight Control(Pitch/Roll/Yaw)	60	0
Cancelled Due to Long Repair	88	Cat II Weather at Takeoff	54	Speed Control System	14	0
Gate Departure	57867	Cat III Weather at Takeoff	159	Primary Compass System	45	42
Dispatch Within 15 Minutes	55011	VFR Weather on Approach	53825	Backup Compass System	13	11
Scheduled Flight Time Exceeded	44353	Cat I Weather on Approach	3861	Attitude Reference	62	49
Divert to Alternate Airport	33	Cat II Weather on Approach	56	Air Data Computer System	22	19
ILS Failure	54	Cat III Weather on Approach	125	Altimeter	25	20
Hold for Takeoff Clearance	39419	Cat III Takeoff Capability	0	Airspeed	7	6
Hold for Landing Clearance	36939	Cat II Takeoff Capability	0	Primary Communications	44	40
Low Fuel Priority Landing	0	Cat I Takeoff Capability	57867	VHF NAV Receiver	73	52
Alternate Takeoff Runway Used	6530	Cat III Landing Capability	0	Backup Radio NAV	55	0
Alternate Landing Runway Used	6572	Cat II Landing Capability	0	Marker Beacon Receiver	11	0
Cancelled Due to Weather	148	Cat I Landing Capability	57826	DME	135	110
				Radio Altimeter	10	0
				ATC Transponder	33	27
				Weather Radar	90	0
				Flight Recorders	44	36
				Flight Interphone	4	4
				Instrument Comparison/Warning	16	0
				Additional Avionics	54	43
				Air Conditioning	162	150
				Oxygen System	43	41
				Hydraulics System	16	15
				Electrical System	6	5
				Fuel System	10	10
				Engines	21	17
				Additional Mechanical Items	727	685

TABLE 19. SUMMARY OF TWO SIMULATIONS WITH DIFFERENT SCHEDULE EXTENSIONS

	+5 Minute Increased Block Time	Minimum 20 Minute Gate Stop
Dispatch Reliability	94.94	95.08
Departure Delays 1-5 min (%)	5.33	2.51
5-15 min (%)	2.93	1.80
>15 min (%)	5.06	4.92
Number of Items Failed	1761	1810
Number of Daytime Repairs	1389	1393
Repair Delay (%)	1.46	1.28
Weather Delay - Takeoff (%)	1.09	1.14
- Landing (%)	.27	.26
Mean Fuel per Leg (lb)	3603.7	3604.3
Cancel for Long Repair	90	88
Cancel for Weather	140	148
Divert to Alternate Airport	38	33

EXAMINATION OF MLS COVERAGE REQUIREMENTS FOR STOL OPERATIONS

The purpose of this analysis was to examine the suitability of the proposed microwave landing system (MLS) coverage for future STOL operations. The RTCA subcommittee 117, in defining the proposed MLS, identified several configurations with varying coverage, accuracy and data rates allowing individual airports to select the most cost effective configuration. Coverage ranges from $\pm 20^{\circ}$ to $\pm 60^{\circ}$ in azimuth and from 8° to 20° in elevation. This wide angle coverage will allow precisely controlled, arbitrary flight paths in the terminal area to facilitate noise abatement and sequencing and metering. Emphasis in this report is primarily on azimuth angle coverage requirements. A precise evaluation of coverage requirements is impossible at this time because the requirements are so dependent on future ATC procedures, quality of new navigation and surveillance systems, airport configurations and progress in achieving quiet engines. This report identifies the major factors influencing coverage and draws some tentative conclusions based on the projected STOL operational environment.

Factors Influencing Coverage

The increased azimuth and vertical coverage proposed for the MLS should provide at least two major benefits.

(1) Arbitrary lateral paths (within the MLS coverage) can be flown precisely, allowing aircraft to be directed over noise insensitive areas. In addition the greater vertical coverage will allow steeper approaches reducing noise footprints.

(2) Metering and sequencing can be greatly facilitated if all aircraft do not have to fly along the extended runway centerline for a major portion of the approach. If, instead, some of the aircraft can join the common path as close as practical to the runway threshold, then the adverse effect of speed difference on capacity can be minimized. In addition, the quality of the position information will allow aircraft to adjust the touchdown time with either time or path control to maximize runway capacity.

This report deals primarily with the azimuth requirements for improved metering and sequencing. It is believed that the azimuth coverage required to fly noise abatement paths will not generally be the constraining factor because of the possibility of steep approach paths and the likely introduction of quieter engines. The most severe demands on MLS coverage will likely occur at major hub airports equipped with independent, parallel runways and ARTS III automation enhanced to include automatic sequencing, spacing, metering and conflict detection. The effect of independent parallel runway operations will be to delete half the available airspace from normal operations for each runway. It is this case that is examined in the following sections.

STOL Flight Paths in the Terminal Area

At the high density airports, STOL aircraft will very likely operate in the airspace closest to the runway. The slower STOL airspeeds provide shorter turning radii and greater maneuverability within a limited airspace. In addition, if STOL aircraft can operate closest to the runway threshold, then total flight times can be minimized when the landing direction is not the same as the en route approach direction. This is particularly important for commercial STOL aircraft because of their economic sensitivity to schedule delays.

Maneuvering Limitations Within MLS Coverage

The maneuvering limitations within the MLS are dependent on the aircraft bank and bank rate limits and airspeed and the maximum wind velocity. Appendix B contains a set of plots showing the maneuvering limitations for numerous aircraft conditions and for variations in MLS coverage and common path length. Those plots were generated on the assumption that the aircraft entered the MLS coverage with wings level and began the maneuver one second later.

The maneuvers shown in Appendix B are not practical. However, they do reflect the shortest distance from the MLS azimuth antenna at which an approach is possible without a go-around. Coupled with the navigation uncertainty prior to entering the MLS coverage, this information allows the choice of nominal or desired paths which will have little likelihood of a go-around. That is, nominal paths must be selected to enter the MLS at a range greater than the minimum maneuvering constraint by an amount sufficient to assure a low probability of a go-around. Thus, the nominal or desired path might be two to four standard deviations (of the navigation uncertainty distribution) beyond the minimums indicated. A more complete description and analysis of the plots is given in Appendix B.

MLS Coverage Required for Time Adjustment

Precise sequencing and metering will depend on accurate time control to achieve a maximum safe landing rate. Time assignments will be given through the air traffic control system. The degree to which ATC participates in the velocity and/or flight path controls to achieve the time assignment will depend on:

(1) The aircraft flight control system and navigation capability

(2) The quality of navigation aids (MLS, VOR/DME, satellite, etc.)

(3) The surveillance accuracy

(4) The ATC communication and computational limitations.

At the two extremes, ATC could provide a landing time assignment somewhere in the terminal area and expect the aircraft navigation and control system to achieve that time without further support (other than conflict detection). On the other hand, ATC could provide heading and velocity commands as necessary. In practice, both techniques will likely be used, with the better equipped aircraft using the former (with the possibility of preferential treatment as motivation) and lesser equipped aircraft requiring numerous commands to achieve the desired result. For aircraft which will control time of arrival using onboard navigation and control equipment, there must be sufficiently accurate navigation aids to estimate position and sufficient time to null errors. The MLS will have sufficient accuracy. The amount of coverage required will depend on the maximum time errors which must be accommodated. If time assignments are not given until the aircraft reaches some position fix within the MLS coverage then as much as one minute of time adjustment may be required. If, on the other hand, final time assignments are given earlier in the terminal area, the required time adjustment within the MLS will be dictated by the combination of state estimate and control errors outside the MLS region. These errors are discussed further in later sections of the report.

The purpose of this section is to define the MLS coverage required as a function of time adjustment. Time of arrival can be adjusted by modifying the flight path direction or by changing velocity. Each technique is considered separately.

Flight Path Control.- Numerous path stretching techniques have been postulated. The fan pattern, referred to in several reports and described in a Collins report[2], is very attractive because of its simplicity and compatibility with existing procedures. Figure 11 shows a typical pattern. The longest path available is flown normal to the runway centerline with a 90 degree turn to the final path. The shortest is flown directly to the common path gate. Variations on this pattern are possible, but they result in the same time adjustment capability when restricted to 90 degree turns or less. For purposes of this discussion, the starting fix point must be somewhere within the MLS coverage. Whether this is an unchanging point in space or a point adapted to each aircraft's entry to the MLS is not clear. In any event, the point is effectively a few seconds within the coverage allowing sufficient time to settle pre-MLS errors and compute the required path.

A typical flight path of the fan family, as shown in Figure 12, is composed of three segments; approach to the common path, turn, and flight along the common path. The required geometric and aircraft variables to compute time and distance are:

x, cross track position of the initial fix point,

y, along track distance from the initial fix point to the common path gate,

α, angle between the initial approach and the common path, (note that this angle can range from a maximum of 90 degrees to a minimum of $\tan^{-1} x/y$. The lower limit is approximate since it doesn't account for the distance needed to turn.)

R, aircraft turn radius,

V, aircraft velocity, and

φ, aircraft bank angle.

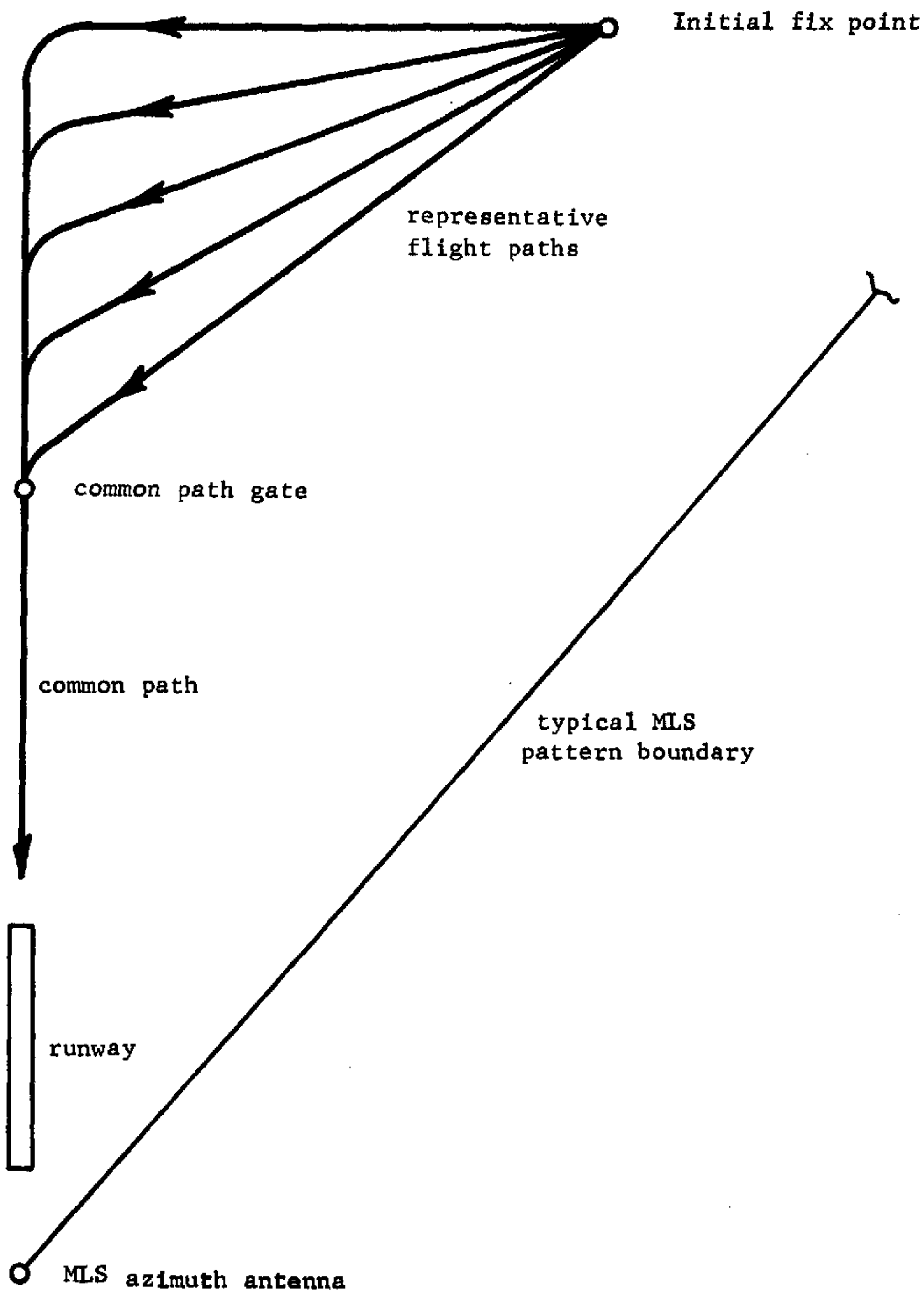


FIGURE 11. GEOMETRY OF FLIGHT PATH PATTERN FOR PATH STRETCHING TIME CONTROL

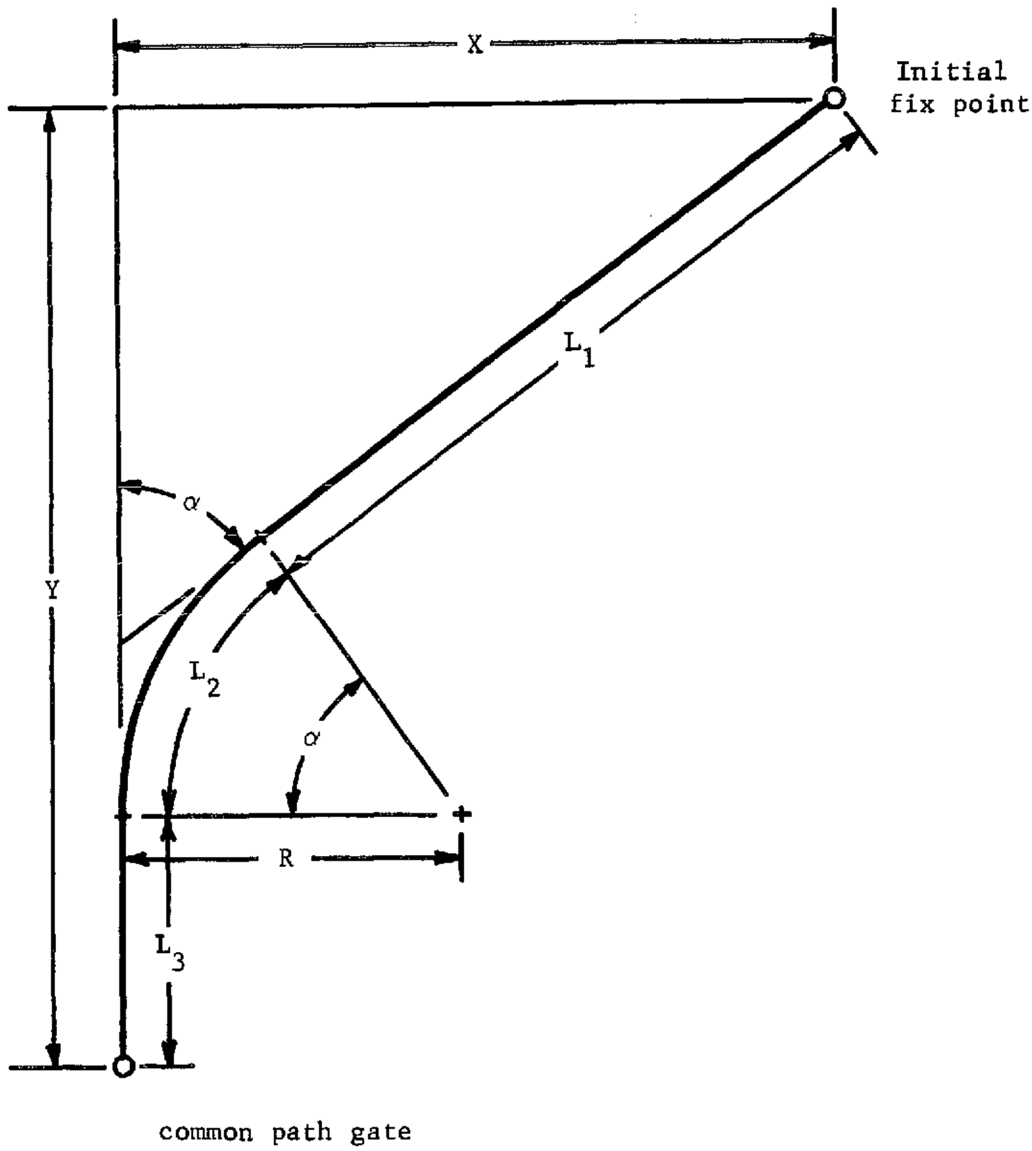


FIGURE 12. REPRESENTATIVE FLIGHT PATH FOR PATH STRETCHING TIME CONTROL

The turn radius of the aircraft is given by

$$R = \frac{V^2}{g \tan \varphi} \quad .$$

The length of each of the three segments shown in Figure 12 is

$$L_1 = [x^2 + (x/\tan\alpha)^2]^{1/2} - R \tan(\alpha/2)$$

$$L_2 = R\alpha$$

$$L_3 = y - x/\tan\alpha - R \tan(\alpha/2).$$

Summing gives

$$L = x(\frac{1 - \cos\alpha}{\sin\alpha}) + R[\alpha - 2 \tan(\alpha/2)] + y \quad .$$

Assuming constant velocity, the time, t, required to fly the path is

$$t = L/V.$$

The maximum time adjustment available is the difference between the longest and shortest paths. This time is computed by substituting the maximum and minimum angles (90 degrees and $\tan^{-1}x/y$ respectively) and subtracting. This provides a time difference, Δt, of

$$\Delta t = \frac{1}{V}[x + y - .43R] - \frac{1}{V}[x(\frac{1 - \cos \alpha}{\sin \alpha})$$

$$+ R(\alpha - 2 \tan \frac{\alpha}{2}) + y].$$

But, for the shortest path

$$x = y \tan \alpha \quad .$$

Thus, in terms of the distance to the common path gate and angle to the initial fix point

$$\Delta t = \frac{y}{V}(\tan \alpha - 1/\cos \alpha + 1) - \frac{R}{V}(.43 - \alpha + 2 \tan \frac{\alpha}{2}) \quad .$$

Figure 13 contains several plots of the locus of constant time adjustment versus initial fix position. Note that each of the three constant time plots are expressed as $\Delta t/2$ reflecting the time increase or decrease about an average nominal. For these plots, a common path length of two miles was assumed. For longer common path lengths, the three curves move up by the amount of the common path increase. Figure 14 shows that the amount of time adjustment available is relatively insensitive to nominal velocity and bank angle.

Speed Control.- An alternative means of adjusting time of arrival is through speed control. The factors affecting time control through speed adjustment are:

(1) Nominal approach speed

(2) maximum and minimum acceptable speeds

(3) acceleration and deceleration capability

(4) path length.

For purposes of STOL aircraft it is assumed that all speed variations must be accomplished before the final turn onto the common path. A reasonable range of speed is from $1.4V_s$ to $1.7V_s$ where V_s is the aircraft stall speed. A typical landing speed is $1.3V_s$. Aircraft certification requirements presently specify that all aircraft must have a maximum flap speed at least 80 percent above the stall speed for that configuration. Assuming that a buffer is required at the extremes of $1.3V_s$ and $1.8V_s$, arbitrary values of $1.4V_s$ to $1.7V_s$ were chosen.

There are four segments to the speed change as shown in Figure 15. During the first segment the aircraft changes speed from the nominal ($1.55V_s$ which is the average of $1.4V_s$ and $1.7V_s$) to either the maximum or minimum speed. The time, t_1, and distance, D_1, covered can be deduced as follows:

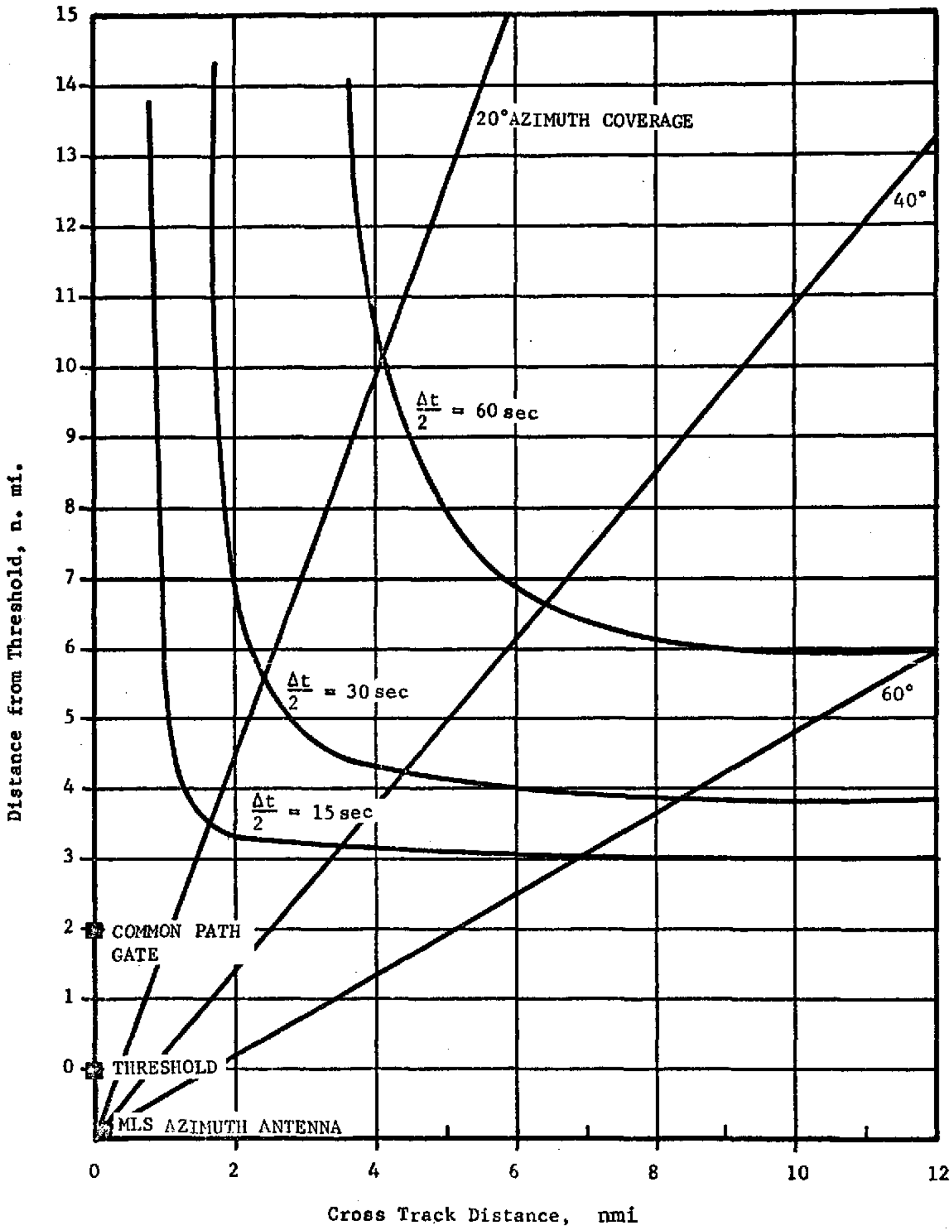


FIGURE 13. TIME CONTROL AVAILABLE VERSUS INITIAL FIX POINT FOR A CONSTANT VELOCITY OF 90KTS & MAXIMUM BANK ANGLE OF 20°

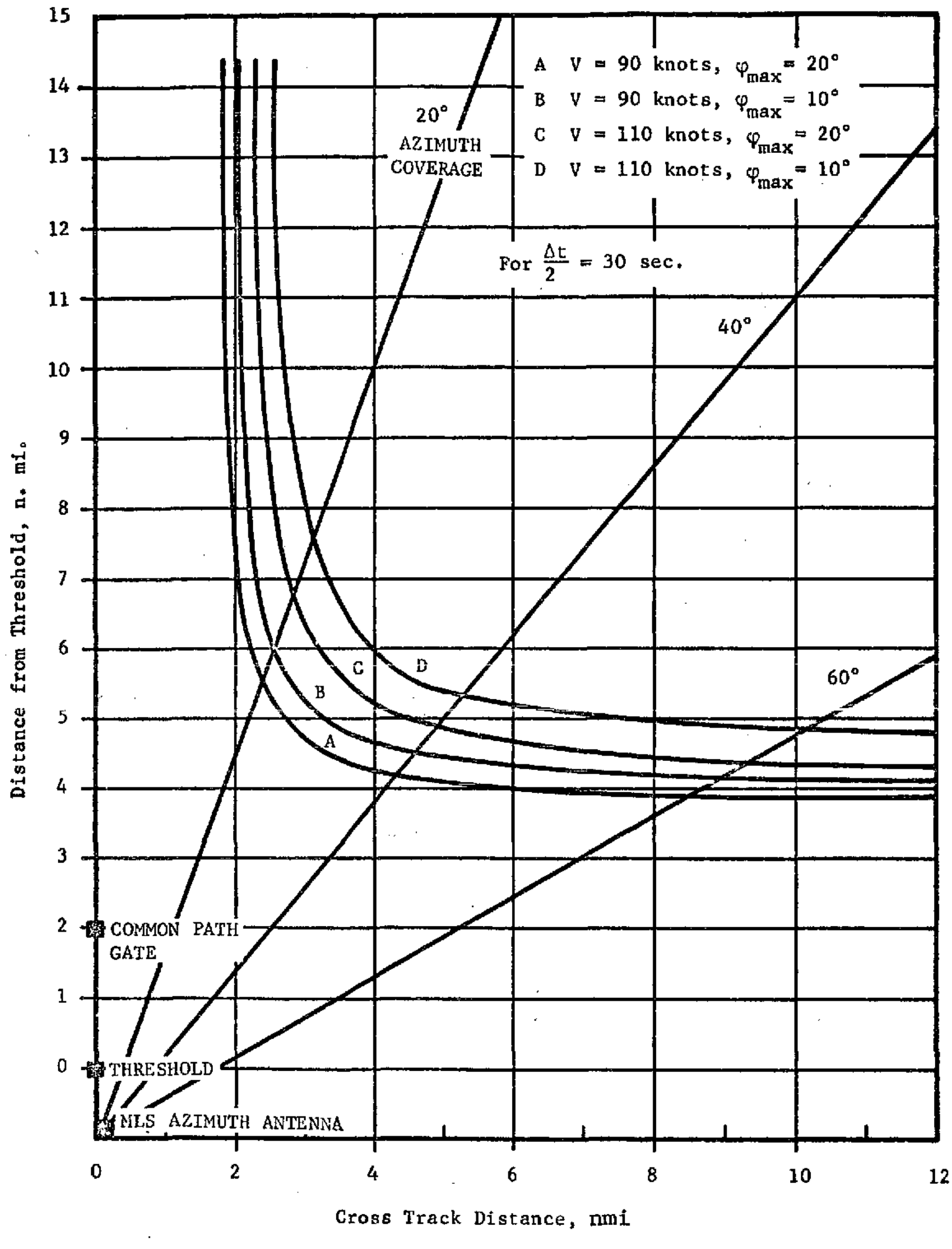


FIGURE 14. SENSITIVITY OF AVAILABLE TIME CONTROL TO VELOCITY AND BANK ANGLE

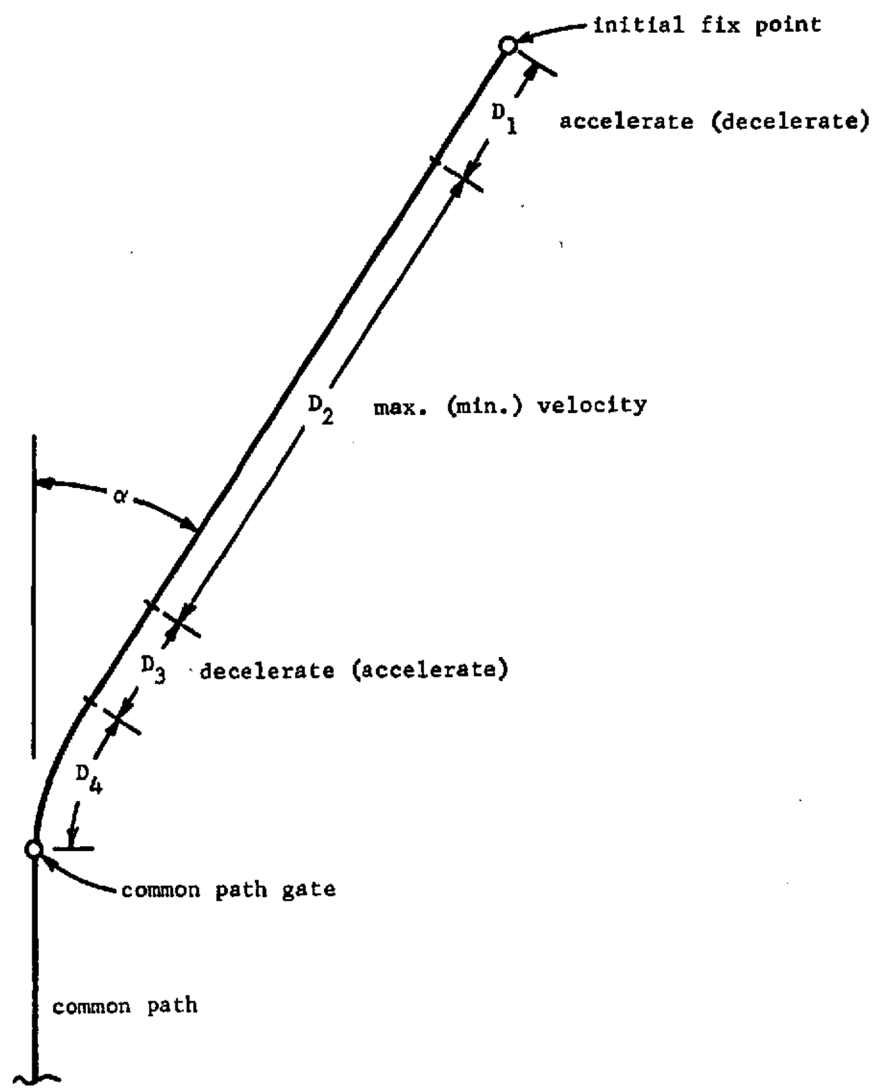


FIGURE 15. FLIGHT SPEED CONTROL PATH FOR TIME CONTROL

$$D_1 = V_0 t_1 + 1/2a\, t_1^2$$

$$V_1 = a\, t_1 + V_0 \quad ,$$

where

$$V_0 = 1.55V_s$$

$$V_1 = 1.4V_s \text{ or } 1.7V_s$$

$$a = \text{aircraft acceleration.}$$

Solving for t_1

$$t_1 = \frac{(V_1 - V_0)}{a} \quad .$$

Substituting into the first equation gives

$$D_1 = \frac{1}{2a} (V_1^2 - V_0^2) \quad .$$

Similarly, for the third segment

$$t_3 = \frac{(V_1 - V_0)}{a}$$

$$D_3 = \frac{1}{2a} (V_1^2 - V_0^2) \quad .$$

The time spent in the second segment, t_2, is given by

$$t_2 = \frac{D_2}{V_1} \quad .$$

Thus the total time and distance in the first three segments is given by

$$D = \frac{1}{a} (V_1^{\,2} - V_0^{\,2}) + t_2 V_1$$

$$t = \frac{2}{a} (V_1 - V_0) + t_2 \quad .$$

Eliminating t_2 from the second equation gives

$$t = \frac{2}{a}(V_1 - V_0) + \frac{D - \frac{1}{a}(V_1^{\,2} - V_0^{\,2})}{V_1} \quad .$$

The nominal flight time, t_0, is

$$t_0 = \frac{D}{V_0} \quad .$$

The maximum time change, Δt, is given by

$$\Delta t = (t - t_0)$$

$$= \frac{1}{a} (V_1 - 2V_0 - \frac{V_0^{\,2}}{V_1}) + D \, (\frac{1}{V_1} - \frac{1}{V_0}) \quad .$$

Figure 16 shows contours of constant time change for a nominal airspeed of 90 kts. and an acceleration capability of 0.1 g. Note that the contours are different for decreasing and increasing time. Figure 17 shows the relative insensitivity of these curves to changes in acceleration.

The speed maneuvers described above are, of course, somewhat simplified but they serve to indicate the rough magnitude of achievable time changes.

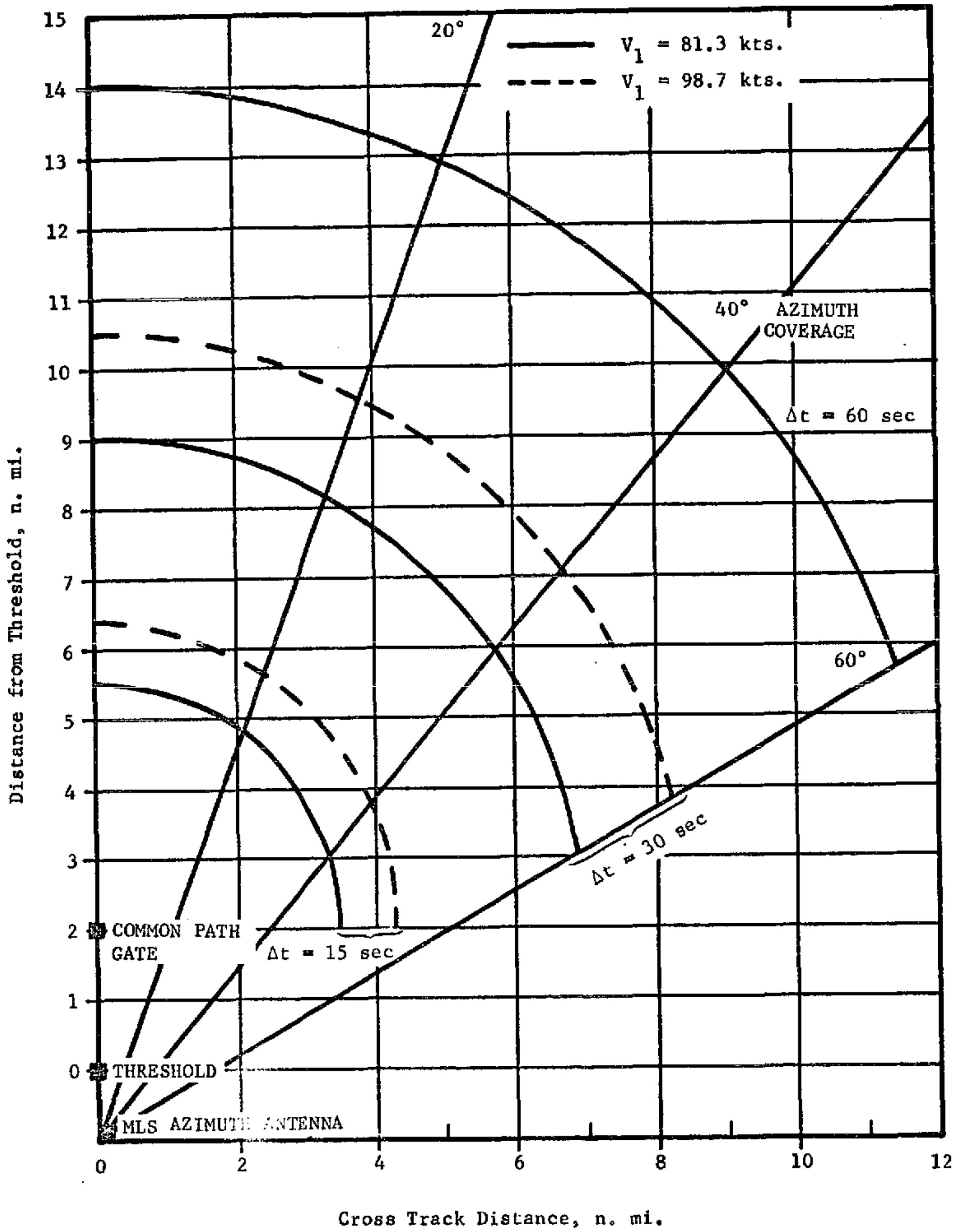


FIGURE 16. MAXIMUM FLIGHT SPEED TIME CONTROL AVAILABLE FOR A NOMINAL SPEED OF 90 KTS AND A MAXIMUM ACCELERATION OF 0.1 G

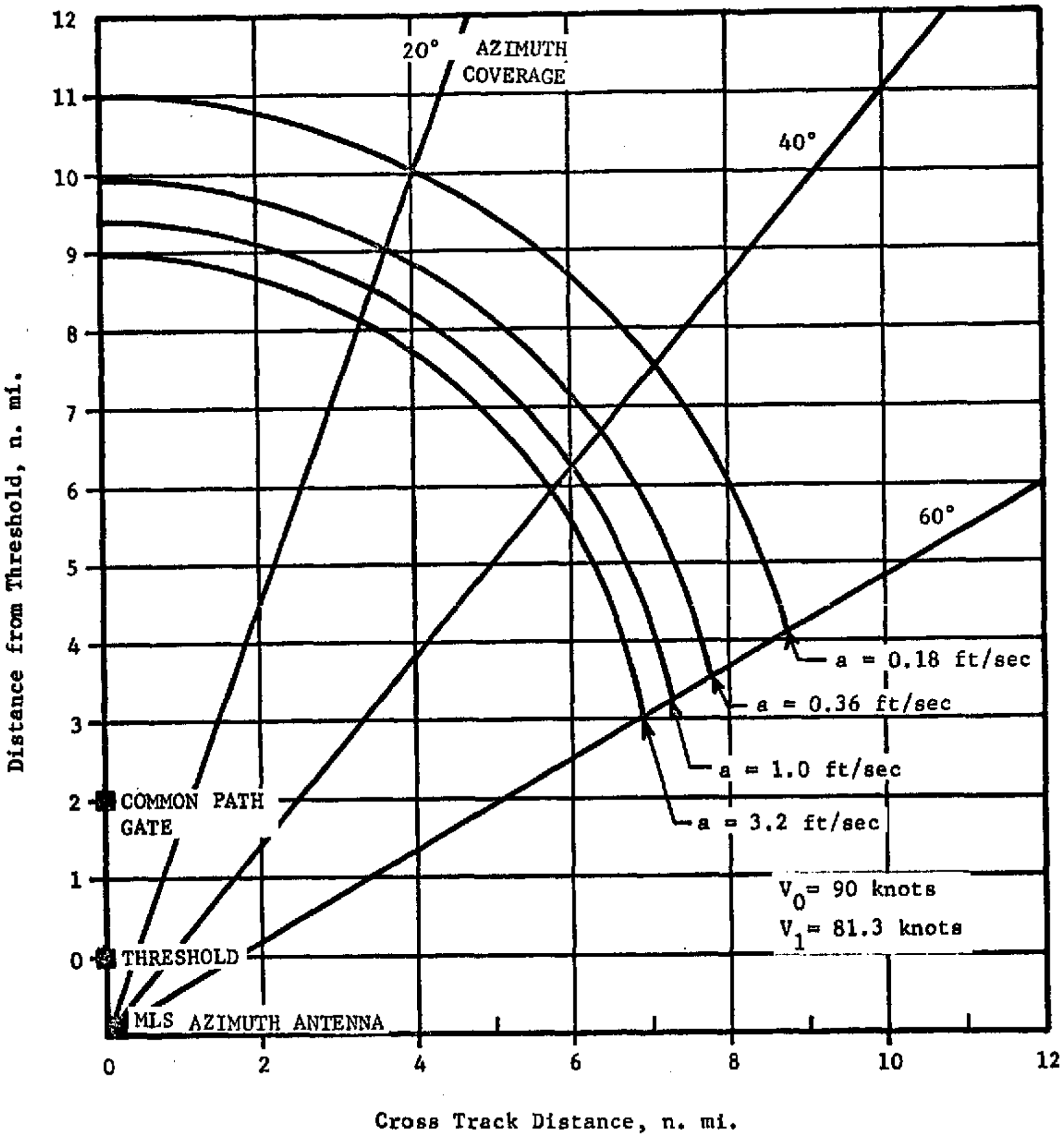


FIGURE 17. EFFECT OF VARYING ACCELERATION RATE ON FLIGHT SPEED TIME CONTROL

State Estimate and Control Uncertainty Outside the MLS

The state estimate and control uncertainty outside the MLS coverage is an important factor in the definition of required MLS coverage. Of particular interest are the cross track and along track uncertainty just prior to entering the MLS coverage. The along track uncertainty divided by the aircraft velocity gives the time of arrival error, dictating the minimum amount of time which must be made up within the MLS coverage. If the pilot is attempting to cross some intermediate waypoint just inside the MLS coverage, then the cross track uncertainty dictates the variation which must be allowed in defining this waypoint.

A cursory examination of these errors was made using the aircraft navigation, guidance and control analysis program (ANGCAP) developed as part of the STOL-OPS programs(3). Since the case of interest is a major high density hub airport equipped with parallel independent runways, it was assumed that a VOR/DME existed near the runways. It was assumed that the aircraft was equipped with an area navigation system capable of complementing the VOR/DME data with air data and heading information. More accurate forms of state estimation are, of course, possible utilizing other VOR/DME stations in the area. However, the case of a single VOR/DME located at the airport represents a likely situation.

Two flight profiles were simulated initially; one path perpendicular to the runway centerline and another approaching 180 degrees to the final path with a turn toward the runway centerline at approximately five miles beyond the threshold. The second profile had smaller errors because the aircraft passed closer to the VOR/DME than the first profile. Thus, only the path perpendicular to the runway centerline was considered further. This path intersected the runway centerline five miles from the threshold.

Table 20 shows the data used for the analysis. Runs were made with a lateral control time constants of 60 and 100 seconds and velocity control time constants of 100 and 200 seconds. Table 21 shows the results at a point two miles from the runway centerline (reflecting the edge of a 20 degree MLS azimuth coverage).

TABLE 20. DATA USED FOR NAVIGATION UNCERTAINTY ANALYSIS

1. VOR/DME standard deviations

	Actual		Filter Model	
	Bias	White Noise	Bias	White Noise
DME Range (nm)	0.14	0.10	0.14	0.10
VOR Bearing (deg)	1.00	1.00	1.00	1.00

2. Winds

	Actual		Filter Model	
	Standard Deviation	Correlation Time	Standard Deviation	Correlation Time
East	10 kts	360 sec	10 kts	360 sec
North	10 kts	360 sec	10 kts	360 sec

3. Aircraft/control transfer functions

Lateral (cross track) - represented as a first order system with a control time constant as specified.

Velocity (along track) - represented as a first order system with a control time constant as specified.

TABLE 21. ERROR ANALYSIS RESULTS

Condition	Error (Std. Dev.)
60 sec. lateral control time constant	0.22 n.mi. cross track
100 sec. lateral control time constant	0.31 n.mi. cross track
100 sec. velocity control time constant	8.6 seconds
200 sec. velocity control time constant	12.4 seconds

Future ATC Environment

The method of sequencing and metering and thus, the requirements for MLS coverage are greatly dependent on future ATC methods. A Mitre report on the upgraded third generation ATC(4) indicates that aircraft will likely be given landing assignments as early as takeoff from the originating airport. The precision of these landing assignments will gradually be reduced from several minutes at takeoff to a few seconds in the terminal area. If this is the case, then time adjustment requirements within MLS coverage should be dependent only on the navigation and control uncertainty outside the MLS. A report on the fourth generation ATC (5) indicates that both navigation and surveillance aids in that time period will be almost as accurate as the MLS, greatly relieving MLS requirements except for landing.

If the upgraded third generation and fourth generation ATC systems occur as indicated in these reports, then the requirements for time of arrival control within the MLS will be dependent only on state estimation and control uncertaintly outside the MLS. However, these improvements are at a very early stage of development and official FAA policies on these improvements have not yet been defined. Significant changes in approach to the problems of sequencing and metering may yet occur before an upgraded third generation capability is implemented. Until these procedures are well defined, the time of arrival control authority required within the MLS will not be fully known.

MLS Azimuth Coverage Required for STOL Operations

The data presented in the previous sections are sufficient to gain some insight into the STOL requirements for MLS coverage. To review briefly, it has been assumed that the greatest demand on coverage will occur at high density airports equipped with parallel independent runways. Parallel independent runways have shown the greatest promise for increasing airport capacity. The presence of parallel runways effectively eliminates half the available airspace from normal maneuvers for any given runway. At the same time, since it is a high density airport, maximizing capacity on each runway will be a major concern. In the future (1985 time period) this will imply the need for precise time of arrival control and a minimum time on the common path for the slower speed aircraft.

The coverage required under these circumstances depends primarily on:

(1) The amount of time adjustment which must be accommodated within the MLS coverage

(2) The position uncertainty at the entrance to MLS coverage

and to a lesser extent on

(1) The common path length

(2) The aircraft maneuver constraints near the common path gate.

Figures 18 to 22 show graphically the airspace required for path control for several conditions. On each figure, a fan family is shown which terminates at the common path gate. Another fan family is shown displaced a half mile further from the threshold. This fan pattern would allow a half mile cross-track error before the time adjustment capability would be affected. The value of one-half mile was chosen based on data in Table 21 as approximately the two-sigma devision of the cross track uncertainty at the MLS entrance. This confidence level is very likely sufficient because the impact of exceeding the two-sigma level is just to reduce the available time of arrival adjustment capability. Also shown on each figure is a closest approach boundary which is based on the data in Appendix B. As indicated above, this has little impact on required coverage unless the nominal MLS entry point is close enough to that boundary to provide a significant probability of crossing the boundary.

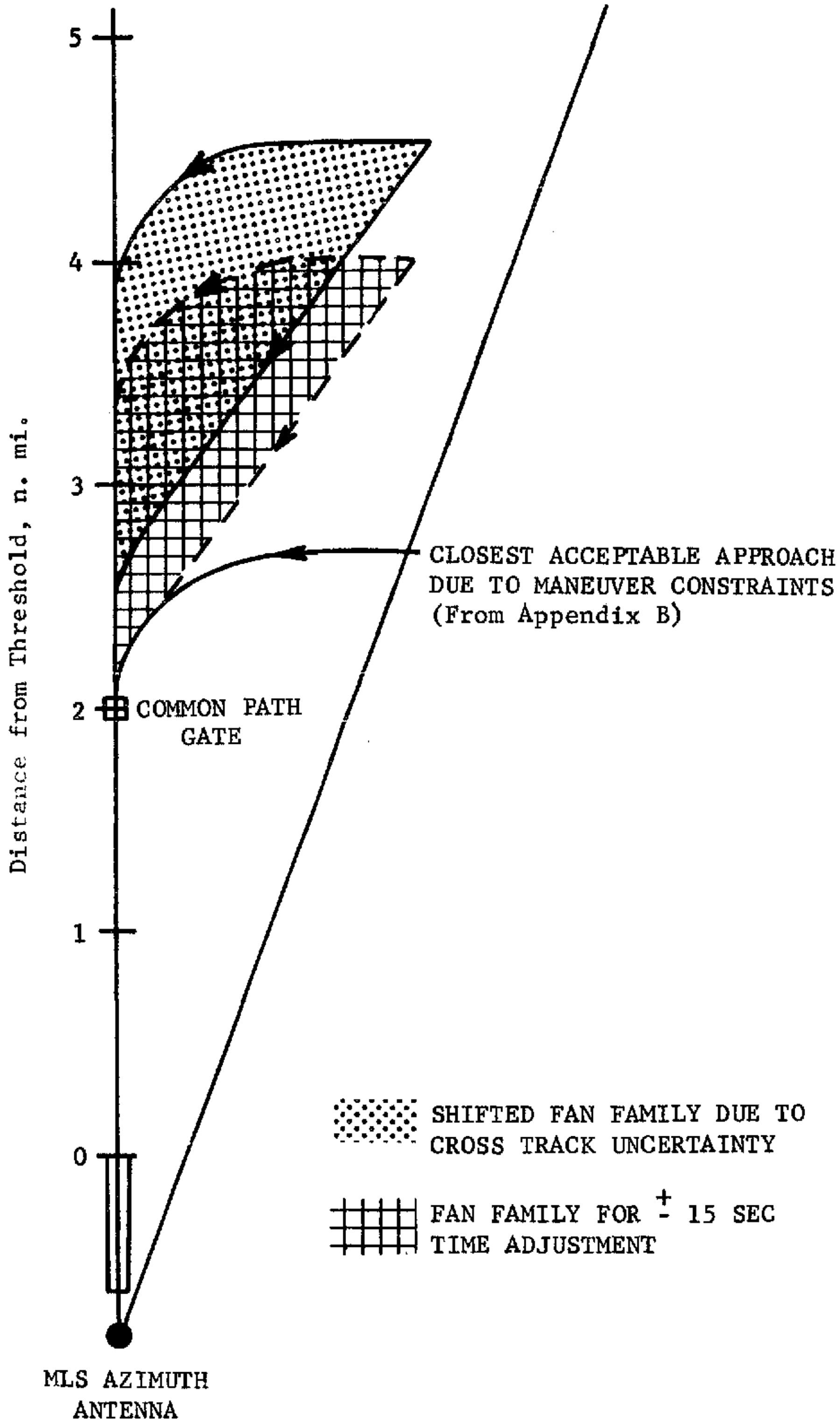


FIGURE 18. MLS AIRSPACE REQUIRED FOR 15 SECOND FAN FAMILY WITH 20 DEGREES AZIMUTH COVERAGE

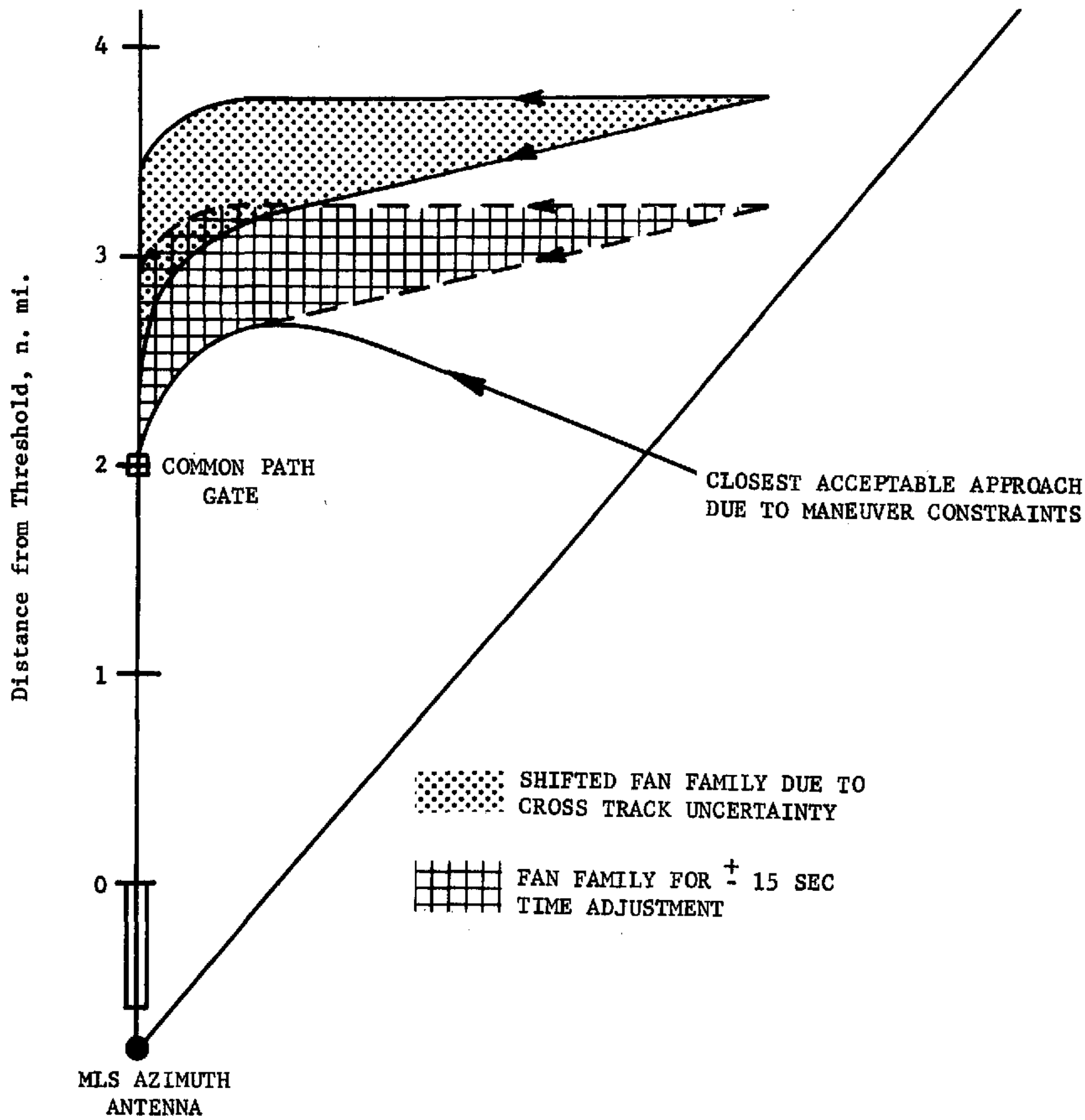


FIGURE 19. MLS AIRSPACE REQUIRED FOR 15 SECOND FAN FAMILY
WITH 40 DEGREES AZIMUTH COVERAGE

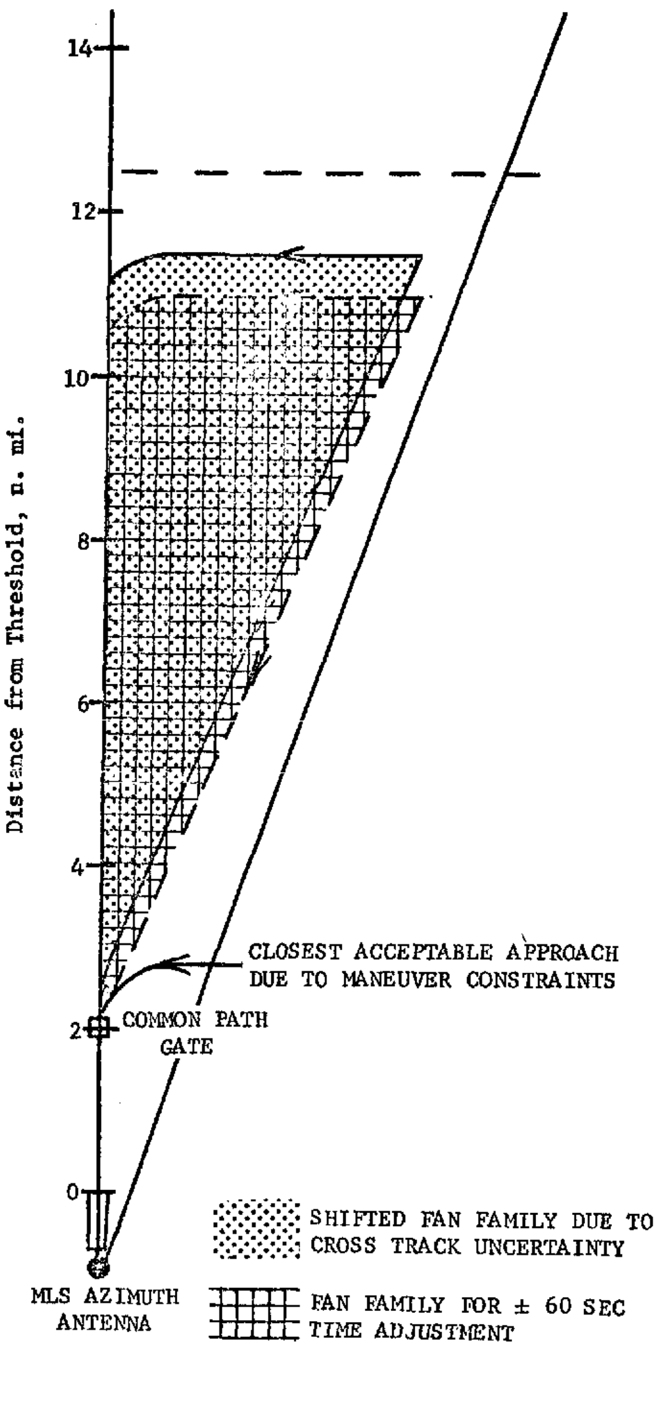


FIGURE 20. MLS AIRSPACE REQUIRED FOR 60 SECOND FAN FAMILY WITH 20 DEGREES AZIMUTH COVERAGE

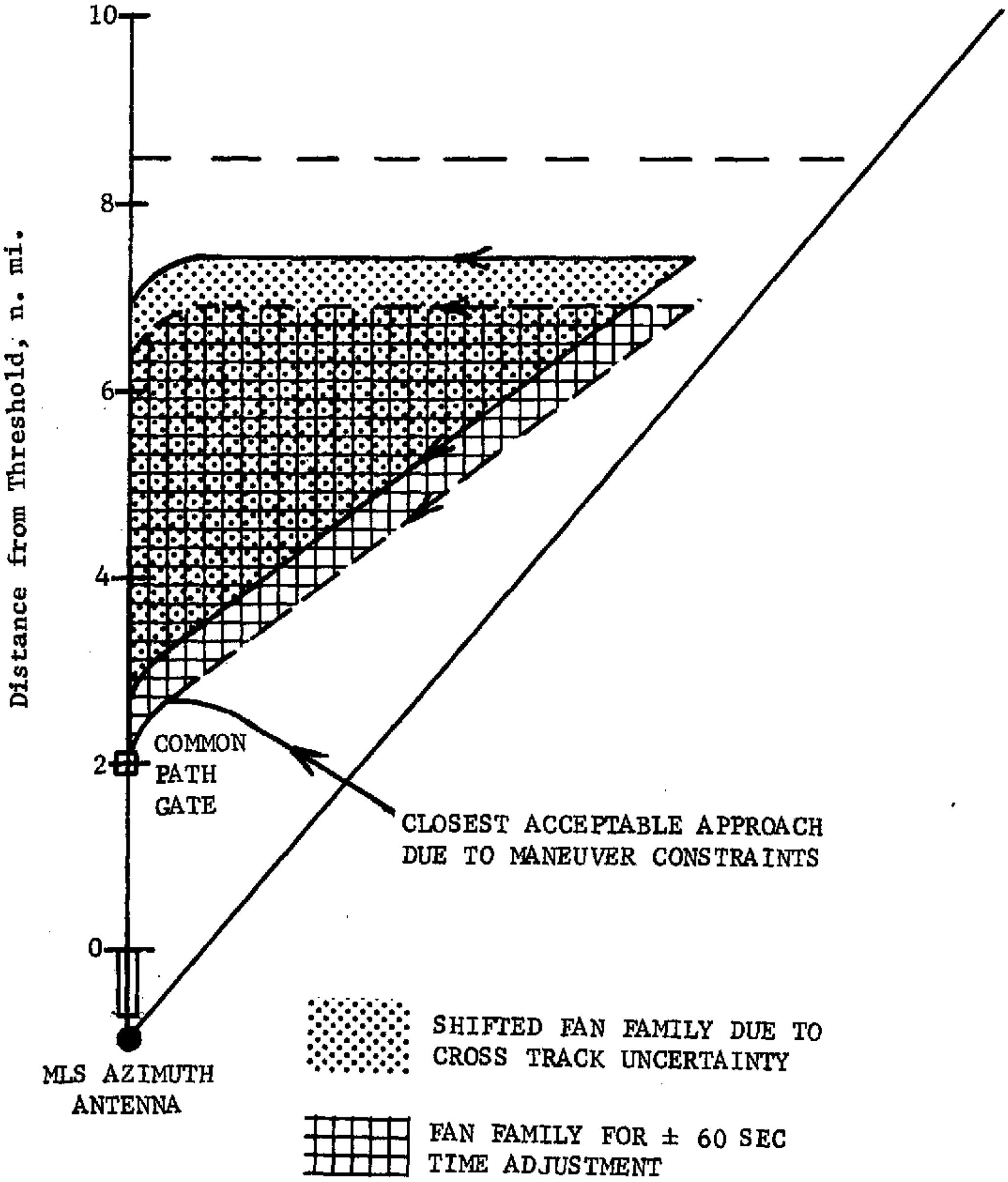


FIGURE 21. MLS AIRSPACE REQUIRED FOR 60 SECOND FAN FAMILY
WITH 40 DEGREES AZIMUTH COVERAGE

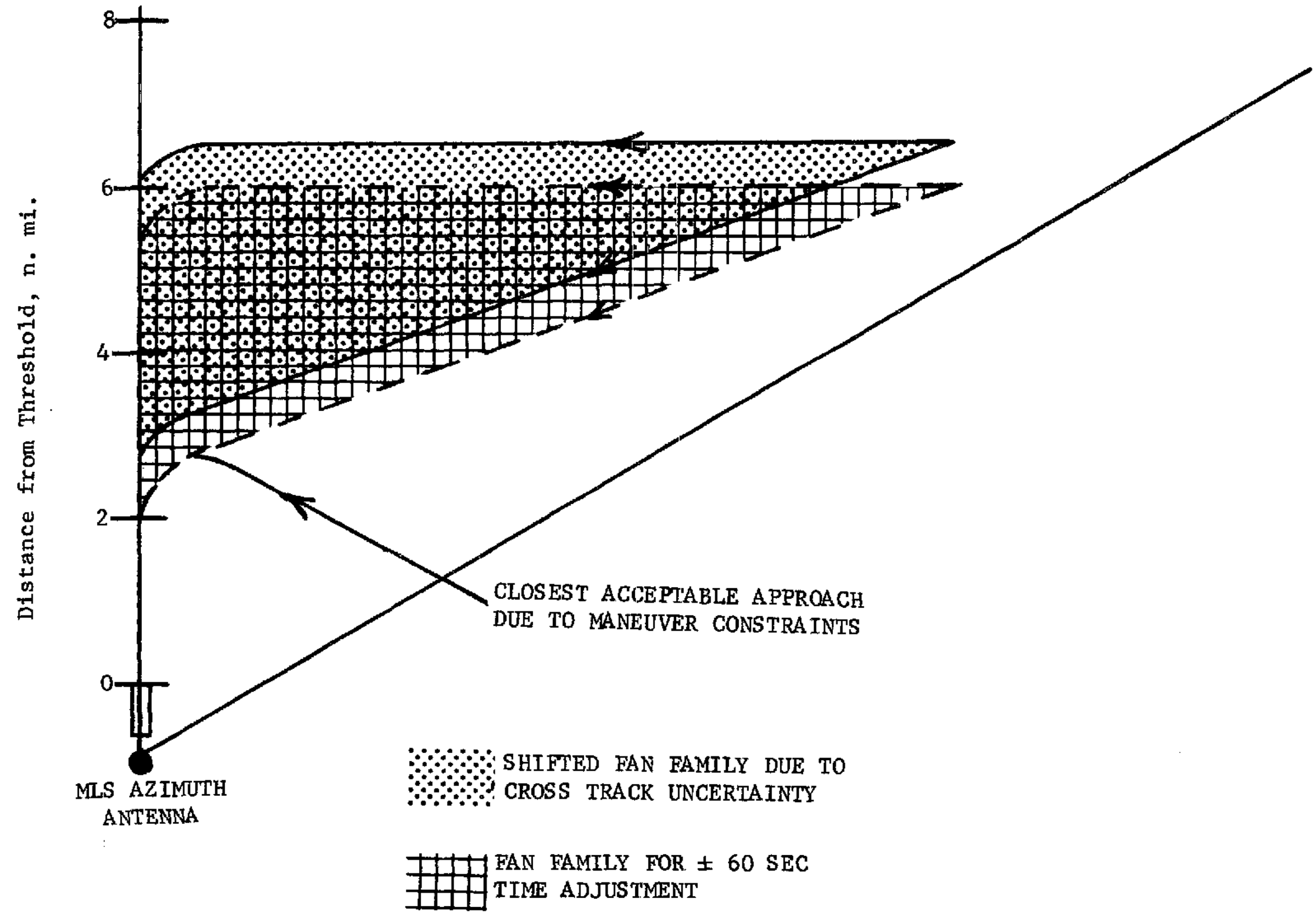


FIGURE 22. MLS AIRSPACE REQUIRED FOR 60 SECOND FAN FAMILY WITH 60 DEGREES AZIMUTH COVERAGE

The common path gate for each of these figures has been set at 2 nautical miles from the threshold. At 2 miles from the threshold a STOL aircraft is 2-8 minutes from touchdown at about 1,500 feet altitude (assuming a 7-degree glide path).

Figures 18 and 19 show a fan pattern with ±15 seconds adjustment capability for 20 and 40 degrees azimuth coverage, respectively. Figures 20 to 22 show a fan pattern with ±60 seconds adjustment capability for 20, 40, and 60 degrees azimuth coverage, respectively.

For the ±15 second fan pattern, the maneuvering range requirements are not much different for 20 and 40 degrees of coverage. For the ±60 second pattern, however, the differences are significant. Twenty degrees of azimuth coverage implies that airspace out to about 12 miles from threshold is required. At 60 degrees azimuth coverage this range reduces to about 7 miles.

At first glance it appears that 20 degrees azimuth coverage would be adequate for STOL operations under the conditions described above. However, there are a number of other factors affecting runway capacity which should be considered. Some of these are discussed below.

Speed Mix.- If aircraft of differing speed ranges are landing on the same runway, then capacity is decreased. This is because a slower aircraft following a faster aircraft will exceed the minimum separation at touchdown. When the slower aircraft reaches the common path, it must have the minimum separation from the faster aircraft in front of it. As both approach the runway their separation increases, thus increasing the time separation between them. It has been shown that almost all aircraft can operate at one of three nominal approach speeds(2). If each of these three speed classes operate in a separate region of the MLS to accomplish time of arrival control, then there should be airspace allocated for a fan pattern for each. For the case of parallel independent runways, it is highly unlikely that more than two speed categories would operate on a given runway, especially the shorter runway which STOL aircraft would be using. Assuming MLS coverage out to 20 nautical miles, there appears to be sufficient area for two fan patterns in all of the cases with the possible exception of Figure 20.

Common Path Length.- One way to reduce the adverse affects on capacity of differing landing approach speeds is to minimize the common path length of the slower aircraft. Tables 22 and 23 show saturation capacity for three common path lengths for two speed mixes. Note that there is a significant increase achieved by reducing common path length. The required common path length can be reduced by minimizing the time of arrival adjustment required within MLS coverage and by increasing azimuth coverage.

Altitude Separation.- It should be noted that separation requirements can be satisfied with altitude as well as lateral separation. In fact altitude separation of differing speed classes in the terminal area may be essential to take best advantage of the minimum separation requirements. It was shown above that capacity improvements could be expected if STOL aircraft joined the common path as close as possible to the threshold. However, during the final turn onto the common path, there is a closest point of approach to an aircraft passing by in front of the STOL. The fact that these two aircraft have their closest point of approach when one is closing on the common path (that is, when there is a significant closing velocity between the two aircraft) would normally dictate greater separation than required if both were on the common path. Thus, the advantage of the shorter common path would be diminished. However, if the two aircraft were separated in altitude, the lateral separation could be minimized. To obtain some feel for relative vertical separation along the common path, note that a STOL on a seven degree glideslope would be at approximately 2200 feet altitude at three miles from the threshold. An aircraft on a three degree glideslope at the same range would be at 950 feet, a separation greater than 1000 feet.

Altitude separation could be helpful in another way. In Figure 20 there is an implication that for ±60 seconds time of arrival authority, approximately 12 miles of airspace from the threshold must be dedicated to this speed class. This also implies long common path lengths for the slower speed aircraft. This can be alleviated by altitude separation, allowing differing speed classes to overlap in the lateral plane.

Speed Control.-Figures 18 to 22 were all drawn on the basis of using path control to change time of arrival. This could also be accomplished using speed control, although generally more airspace is required and a greater pilot workload may be involved. In addition it is possible that some combination of speed and path control could be used to further reduce required airspace

TABLE 22. HOURLY CAPACITY FOR A LANDING APPROACH SPEED MIX OF 50% AT 80 kts., 25% AT 100 kts. AND 25% AT 110 kts.*

Common Path Length (n.mi.) \ Separation at CPA** (n.mi.)	2.0	3.0
2	42.3	28.9
4	39.6	27.6
8	35.2	25.4

* Using the capacity model in Reference 6.

** Closest point of approach.

TABLE 23. HOURLY CAPACITY FOR A LANDING APPROACH SPEED MIX OF 25% AT 80 kts., 37.5% AT 100 kts. AND 37.5% AT 110 kts.*

Common Path Length (n.mi.) \ Separation at CPA** (n.mi.)	2.0	3.0
2	45.6	31.0
4	42.9	29.8
8	38.4	27.5

* Using the capacity model in Reference 6.

** Closest point of approach.

Elevation Coverage

The previous sections have dealt only with azimuth MLS coverage. Elevation coverage is also of interest. The SC-117 subcommittee recommended elevation coverages of 8 and 20 degrees depending on the configuration. There are two aspects of elevation coverage; the maximum elevation of the elevation signal and the maximum elevation of the azimuth signal. STOL aircraft will be quite sensitive to elevation coverage because of their steep approach capability. If STOL aircraft use glide paths which are less than 8 degrees, then there would be sufficient coverage if they made a straight in approach. If, however, a STOL aircraft approaches the runway centerline from some angle and is executing a descent at the same time, then there is a possibility of operating above the coverage. Figure 23 shows where an aircraft would enter the azimuth coverage if approaching at a right angle to the runway centerline and executing a 7 degree descent within an 8 degree coverage. If the common path length is six to eight miles long then it is likely that the aircraft would not start the descent until the runway centerline was reached. However, for shorter common paths this would not necessarily be the case. Thus, 8 degrees of vertical coverage appears to be marginal for STOL operations in a high density environment.

Conclusions

Adequate conclusions regarding the required azimuth MLS coverage for STOL operations are very difficult because of the uncertain data base. For example:

(1) The future ATC procedures for time of arrival control, and thus the requirements for control authority, are very tenuous.

(2) A specific pattern (the fan family) was chosen to determine the airspace required for time of arrival adjustment, yet there has been no policy definition regarding the method to be used.

(3) For much of the data (Figures 18 to 22) a common path length of two miles was used, but it is not clear that this will be an acceptable value.

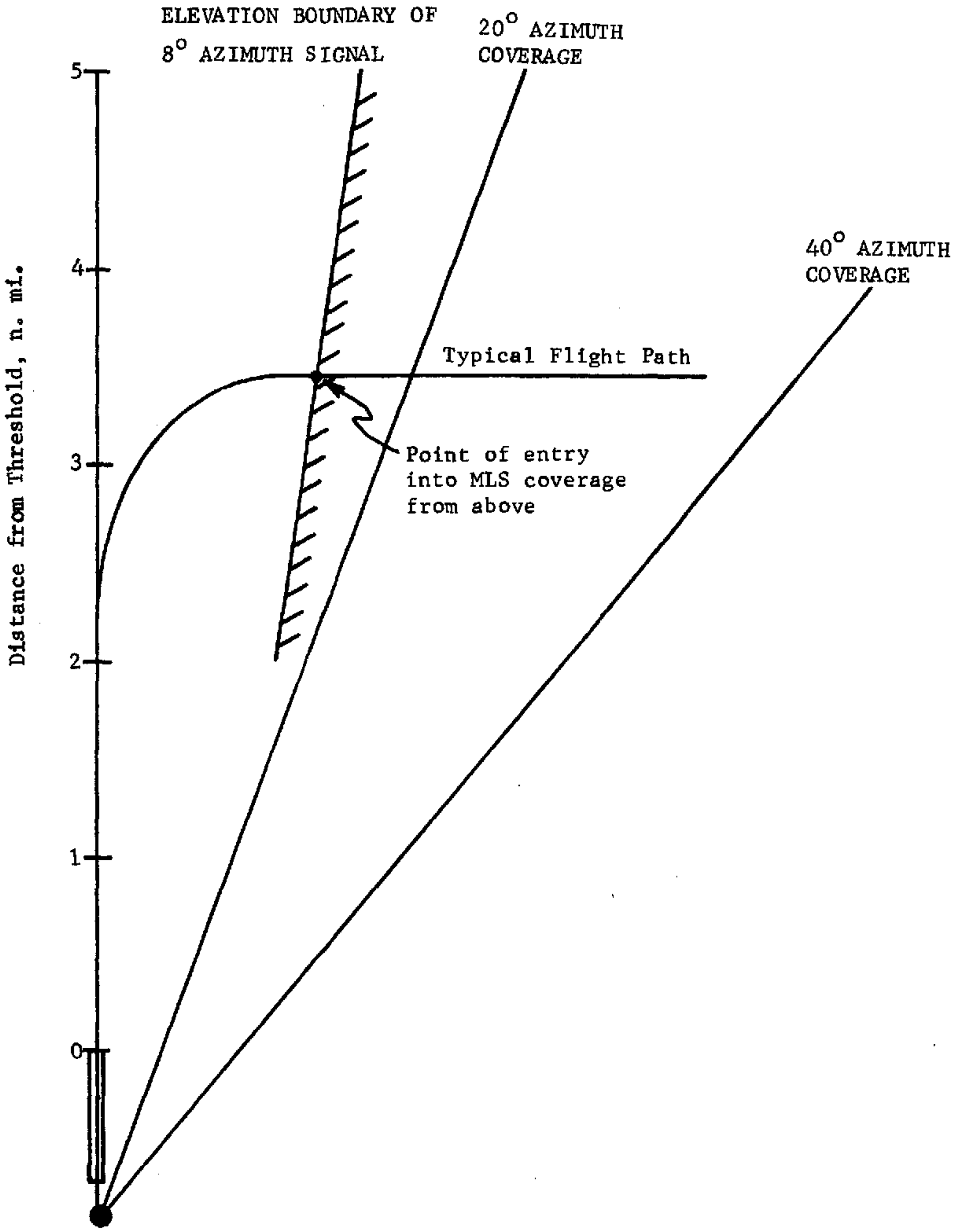


FIGURE 23. BOUND OF 8 DEGREE ELEVATION COVERAGE FOR AN AIRCRAFT EXECUTING A 7 DEGREE DESCENT AND A 90 DEGREE INTERCEPT OF THE RUNWAY CENTERLINE

(4) Use of speed control was not assumed in drawing Figures 18 to 22.

(5) The case of high density parallel independent runways with precise, automated sequencing and metering was assumed to represent the worst case for azimuth coverage.

Despite the uncertainty involved there are certain conclusions that are apparent.

(1) A coverage of ±60 degrees does not appear to offer a significant advantage over ±40 degrees coverage.

(2) A coverage increase from ±20 to ±40 degrees can significantly decrease the required STOL common path length if a large (±60 seconds) time of arrival control authority is required.

(3) A large time of arrival control authority within MLS coverage requires excessive common path lengths for any of the coverages. Thus, there is real advantage in attempting to minimize this required authority with some form of control outside the MLS.

(4) A coverage of ±20 degrees is adequate if the disadvantage of longer common paths can be compensated with altitude separation on the final path.

(5) A coverage of ±20 degrees is adequate if a time of arrival control authority on the order of ±15 seconds is adequate.

(6) Based on the assumptions in this appendix, ±20 degrees of azimuth coverage is adequate for all but the worst case high density parallel independent runway airports. For this case it is marginal.

(7) Eight degrees of vertical coverage is marginal for STOL operations.

APPLICATION OF INS TO STOL

The purpose of this task was to determine the avionics functions that can be provided by an inertial navigation system (INS) or inertial reference system (IRS) for short-haul domestic operations assuming a requirement to operate in Category III weather. In addition, cost and reliability data were to be gathered on existing INS systems for NASA/ARC to use as a baseline in the development of a redundant strapdown inertial reference unit (SIRU).

This task was accomplished primarily through a survey of airlines, aircraft manufacturers, avionics manufacturers, and government agencies. These organizations and individuals contacted are listed in Table 24. The comments received have been segregated into several categories and are repeated essentially as received. Most individuals were quite candid and open in their remarks and generally preferred not to be quoted directly. Thus, the views are presented without indication of the authors. However, the segment of industry (from Table 24) the view came from is indicated after each comment. Several comments will appear to be repeated. In these cases several individuals had the same or similar views and they are repeated to reflect the degree of consensus. Following these comments there is a section of conclusions drawn from the survey.

Data on Existing Inertial Equipment

The present complement of inertial equipment or equipment replaceable by an inertial system aboard Category III equipped aircraft includes:

9 accelerometers (3 for each axis),

3 rate gyros (9 if rate is not derived from the vertical gyros),

3 vertical gyros,

2 compass systems.

TABLE 24. PERSONS CONTACTED REGARDING APPLICATION OF INS TO STOL

1. Aircraft Manufacturers

   Mr. Hal Tobie, Boeing Commercial Airplane Company
   Mr. Al Norwood, Boeing Commercial Airplane Company
   Mr. Bob Adams, McDonnell Douglas Corporation (Long Beach, California)

2. INS Manufacturers and Developers

   Mr. Jeff Amacker, Singer-Kearfott
   Mr. Ron McGraw, Collins Radio Company
   Mr. Loren DeGroot, Collins Radio Company
   Mr. Paul Savage, Honeywell Inc. (Minneapolis)
   Mr. Dick Miller, Litton Aero Products
   Mr. Walt Ebert, Autonetics Division of North American Rockwell

3. Navigation and Flight Control Manufacturers

   Mr. Fred Allgower, Sperry Flight Systems
   Mr. Don McGlade, Sperry Flight Systems
   Dr. Norb Hemesath, Collins Radio Company
   Dr. Gordon Neal, Collins Radio Company
   Mr. John Hall, Collins Radio Company

4. Airlines

   Mr. T. A. Ellison, United Airlines
   Mr. Howard Mehrling, Eastern Air Lines

5. Airline Related Organizations

   Mr. William Carnes, ARINC/AEEC
   Mr. Sig Poritzky, Air Transport Association

6. Government

   Mr. Everett Morris, FAA Flight Standards Service

7. Others

   Mr. Jerold Gilmore, The Charles Stark Draper Laboratory
   Mr. Robert Booth, The Charles Stark Draper Laboratory

Reliability data and approximate costs for these systems are as follows:

	Replacement Cost	MTBF* (hours)	MTBUR** (hours)
Accelerometer	$1,000	96,700	47,500
Rate Gyro	1,000	6,400	3,000
Vertical Gyro	6,000	3,000	1,000
Compass System			
Directional Gyro	3,500	7,700	2,300
Flux Gate	600	180,000	45,000
Coupler	4,200	8,500	3,000
Controller	400	585,000	
Compensator	400		
Rack	850		76,000
Total Compass System	9,950	2,000	1,300

Note that the costs are replacement or spares costs which tend to be about 33 percent higher than for an installed price. Manufacturer quoted prices generally reflect these replacement prices.

The reliability data shown above are taken from field data. With these figures, the cost for a fail-operational autoland (Category III) inertial sensor complement is approximately $50,000 with a mean-time-between failures (MTBF) of 483 hours and a mean-time-between-unscheduled-removals (MTBUR) of 173 hours. (Navigation and Flight Control Manufacturer)

The price of present ARINC 561 inertial navigators is approximately $100,000 each. The reliability specification is 1800 hours MTBF which is almost being achieved. (Aircraft Manufacturer)

Our present experience with gimballed inertial navigation systems shows high but tolerable maintenance costs. They are running about $3.00 per system hour for each INS with costs split approximately equally between the IRS and computer. The accuracy of the systems is more than adequate. (Airline)

A primary advantage of INS in today's operations is reliability. For gimballed systems which have the capability of reverting to an attitude system when the computer fails, the MTBF of the attitude function is about 2500 hours. The computer represents about half of the total INS failures. The ratio of ground to airborne failures is about three to one. (INS Manufacturer)

---

* Mean time between failures.

** Mean time between unscheduled removals.

For one airline the maintenance costs of inertial equipment was as follows:

directional gyro - 15 to 20 cents per operating hour
vertical gyro - 30 cents per operating hour
gimballed INS - $2.75 per operating hour.

The inertial systems are averaging 4200 operating hours per year. This represents an average cost of $11,550 per year for each INS. (INS Manufacturer)

Our price for a full system is $92,000 which includes DME/DME filtered update. There are some improvements which could lead to a 15-20 percent reduction in price. (INS Manufacturer)

Gimballed systems have about reached the end of the line in cost and reliability. The MTBF ranges from 800 to 1700 hours and the cost ranges from $85K to $110K. Maintenance costs range from $2.50 to $3.00 per hour. (INS Manufacturer)

The LTN51 sells for $106K, has an MTBF of 1200 hours and a half mile per hour performance. The LTN72 sells for $98K. (INS Manufacturer)

Existing INS reliability breaks down as follows (based on several years airline experience):

- total system MTBF is about 1200 hours
- the ratio of ground to air failures is about three to one
- half of the failures are in the computer.

Thus, the reliability of basic attitude information while airborne is greater than 3000 hours MTBF. (INS Manufacturer)

Flight Functions Provided by an Inertial System

An INS could allow removal of all other inertial instruments. In addition, the flight control system could be significantly simplified with much improved performance. Present ILS and VOR capture schemes tend to be complex and perform marginally. Tracking performance in a coupled mode on VOR's and presumably on area navigation systems utilizing VOR/DME is marginal in terms of the bank activity. An INS updated with radio aids provides excellent coupled performance. INS is inevitable in the domestic environment if for no other reason than the improved flight performance and safety aspects of reduced in-flight pilot workload. (Navigation and Flight Control Manufacturer)

INS is needed in Category III conditions, primarily to monitor the ground system. In addition, the vertical gyro can be poorly erected after a steep descent into the terminal area. This poor erection to a false gravity vector will cause standoff in the flight control system. For STOL vehicles this problem may be more severe because of more maneuvering in the terminal area and short common path lengths. An INS is not susceptible to this problem. An INS would also be very useful to smooth dropouts in the microwave landing system (MLS) signal during curved path maneuvers. (Aircraft Manufacturer)

We have no projections for a domestic need for an INS. The navigation computer (presumably area navigation) will be implemented but the addition of the inertial reference system is too expensive both in initial and recurring costs. (Airline)

National Airlines has been quite successful in coupling to an area navigation system without INS in both the VOR/DME and DME/DME modes. There are cases where a VOR/DME combination causes more bank than is acceptable but they are generally pleased with the system. (Navigation and Flight Control Manufacturer)

My personal opinion is that as INS becomes less expensive it will be utilized in the domestic or short-haul environment, not because it is essential, but because it has so many nice features. I would compare it to auto power steering. We couldn't show that it's cost effective but we wouldn't do without it. (Navigation and Flight Control Manufacturer)

We do not feel that INS is required as part of the Category III Autoland system. We feel that adequate protection from ground system failures is provided in the aircraft through rate limiters and deviation sensors. We have experienced some problems with vertical gyro standoff. However, these tend to be nuisance problems rather than serious flight control or safety problems. (Navigation and Flight Control Manufacturer)

I see no essential requirement for INS in short-haul operations. Implementation will depend heavily on first cost and maintenance costs. (Airline Related Organization)

INS will be implemented in the domestic market only if the computer and sensors are used to serve a total system function encompassing SAS, attitude, navigation, etc. (INS Manufacturer)

There is still a big question whether Schuler-tuned inertial attitude information is needed for Category III. Vertical gyros are satisfactory now qualified by a limitation on maneuvers prior to landing. It isn't clear that the VG/DG combination is good enough when curved paths and short final common paths are used. (INS Manufacturer)

I can't see that INS can pay its way on the next generation STOL without a breakthrough in cost and maintenance. The new MLS with curved paths and the introduction of area navigation leave the INS picture unclear primarily because we don't know whether present attitude sensors will be satisfactory. (Airline)

I would be concerned if an integrated redundant INS was part of fail operational autoland, that integrity would be difficult to prove without complete separation of redundant systems. (Airline)

We encourage the use of INS for smoothing anomalies and providing a greater degree of safety on the landing approach. In the future, city center to city center V/STOL all weather operations may require INS quality attitude for certification. (Government)

We think of the strapdown as an integrated system with the computer serving flight control and management functions with self contained navigation as a free extra. (INS Manufacturer)

I have difficulty seeing any short-haul requirement for INS. Vertical gyros with reduced drift rates may be able to handle the improved verticality requirements for STOL in Category III conditions. (INS Manufacturer)

I see nothing unique about STOL requiring INS. The present cost of $75K-$100K without high reliability and easy maintenance is not likely to find a place in short-haul. (Airline Related Organization)

INS must be able to demonstrate that it can replace a set of instruments of comparable cost. The autoland or autopilot requirements will dictate the cost airlines will be willing to pay for conventional instruments. When INS is available in that cost range then the safety, performance, and flexibility offered by INS will be immediately adopted. A price range of $25K-$35K would likely be acceptable. One must consider sharing both instruments and computer, that is, treating it as a total system. The airlines will not buy better performance. (Aircraft Manufacturer)

General Comments About INS

I am skeptical about the availability of strapdown systems. People have been claiming that flight systems are only a year away for too long. (Airline Related Organization)

There will be problems substituting a single system (INS) for several smaller systems (VG, DG, accelerometers). If a vertical gyro fails now, heading is not affected, whereas, an INS failure could remove all inertial capability. In addition spare requirements and maintenance are much more formidable for a complete system. An integrated redundant system, in particular, raises questions regarding spare requirements. (Airline Related Organization)

When an INS is procured, fleet commonality will be an important consideration which may have implications about the performance required for those airlines which have both short-haul and long-haul oceanic flights. (Airline Related Organization)

Gimballed systems are too expensive to find a market in domestic short-haul. (INS Manufacturer)

Some of the problems we are having with INS in the field are:

(1) Ease of self check and easy removal leads to increased removal rate even though the INS might be all right

(2) Unreliable aircraft cooling

(3) Poor procedure including moving before completion of align and bad input. (INS Manufacturer)

INS has been easy to sell for general aviation jets. The biggest problem there is space, peak power available for heaters, and weight. They take a dual system whenever they can. The INS gives them a great deal of flexibility allowing them to go anywhere. (INS Manufacturer)

INS is a solid requirement for long range new aircraft. (INS Manufacturer)

All airlines are concerned about reliability. Present redundancy techniques are complex and costly. The industry would be very interested in techniques for achieving redundancy reliably. (Airline Related Organization)

We think we can satisfy a fail operational requirement with two inline monitored gimballed INS rather than three systems. (INS Manufacturer)

Projected Costs of New Gimballed Platform INS

The price of new gimballed systems will not go down much further. (INS Manufacturer)

We can't push gimballed technology much further. The single area of projected improvements is in electronics, not mechanics. Analog circuits tend to fail twice as often as digital. Thus, the logical approach is strapdown if the sensors can take the environment. I think the laser gyro is about 10-15 years away for airline use. I understand that there are problems with calibration stability, day-to-day repeatibility and total lifetime. In the interim, strapdown systems will utilize hinged and rotor instruments and ESG's. (INS Manufacturer)

We are developing a small gimballed inertial system which should be available in 1976-77 for about $80K. (INS Manufacturer)

Projected Cost of Strapdown Systems

Strapdown is clearly the way to go for future commercial applications because of the reduced cost and increased reliability which can be achieved. We feel that $50,000 per system is near (3-5 years) and $35,000 per system is readily achievable. (Aircraft Manufacturer)

We are looking heavily at strapdown as a means of reducing price. With existing hardware the price should be about $55,000 per system. (INS Manufacturer)

We expect that our strapdown system, acting as a non-redundant navigator will be priced from $40,000-$50,000. We expect to flight test our system in late 1974 or early 1975. (INS Manufacturer)

I would expect strapdown systems to be priced initially between $65-$70K with a minimum threshold of $35-$50K. (INS Manufacturer)

We have been looking at strapdown but it still has lots of drawbacks such as computer glitches due to power changes especially on final approach. A gimballed system can still provide attitude if the computer fails. My view of strapdown costs with state of the art equipment is as follows:

gyros	- \$6K-\$8K each
accelerometers	- \$2K each
computer with 4-5K memory	- \$10K.

When you add packaging and profit, initial field support, etc. the minimum price is \$50K-\$60K. (INS Manufacturer)

We have just lab tested a strapdown system demonstrating performance better than one mile per hour. We are hoping to have a first commercial system ready for flight test in December, 1974. We have a cost goal of \$35K per system in quantities of 1000 or more. (INS Manufacturer)

The state of the art exists to produce an inexpensive strapdown in 4-5 years (\$35K or less). (Aircraft Manufacturer)

Requirement for Category III Autoland Capability

We're not sure whether Category III capabilities will be procured on new aircraft. (Aircraft Manufacturer)

On our new wide body jets we are not maintaining Category III conditions. If they don't have to be fail operational we can get by with fewer spares and the periodic maintenance costs are not as high. We are taking a "wait and see" attitude about the direction Category III will take. (Airline)

Category III is proving to be a very high cost maintenance item for us. (Airline)

Summary and Conclusions

Gimballed inertial navigation systems presently in service have the following characteristics

Replacement Cost	\$85K - 110K
Performance	Better than one mile per hour
Reliability	1000 - 1500 hours MTBF
Maintenance Cost	\$2.50 - \$3.00 per system hour. This represents approximately \$12,000 per year for each installed INS.

These systems generally have a capability to revert to an attitude mode if there is a computer failure. Since the computer represents about half the total INS failures, the attitude function has a reliability greater than 2000 hours MTBF. The in-flight failure rate is even less than implied by this MTBF. Many of the failures are detected on the ground during alignment. If a system can't align within certain tolerances it is removed. Faults may have occurred during previous flights but the performance degradation, particularly to satisfy attitude requirements, might not be significant. Thus, a significant proportion of failures (three to one) appear to be ground or turn-on failures.

The cost of gimballed systems will not improve significantly. It is highly unlikely that any new gimballed systems could sell for less than $75,000. This conclusion is generally accepted by all of the INS manufacturers consulted, even those heavily committed to gimballed systems.

The airlines feel that INS is very expensive both for initial buy and recurring costs. Maintenance is difficult because of the system complexity and spares are expensive. Airlines will not purchase INS for short-haul unless its cost and maintenance requirements are competitive with the equipment being replaced. In other words, airlines will not pay for increased safety, reduced pilot workload and increased flexibility unless

(1) A regulating agency imposes the requirement

(2) The improvement is clearly cost effective

(3) Technical requirements demand the improved performance.

There is no essential requirement for INS in the short-haul (500-1000 miles) over-land operations. There is still a controversy about the need for INS in the Category III Autoland. However, two manufacturers have been or are about to be certified for Category III without INS. The arguments for INS generally center around the need for more effective monitoring of the ground system, more reliable attitude information, freedom from the nuisance of beam interference or data dropout, and improved navigational capability in the event of autoland system failures and missed approaches. The regulatory agencies are (and should be) reluctant to force additional hardware requirements such as INS as part of Category III certification. Category III, as presently implemented, is expensive and requires a great deal of periodic maintenance. Requirements for additional, more expensive equipment would further reduce the likelihood of widespread Category III implementation on future generation aircraft.

STOL aircraft may require Schuler-tuned attitude information rather than a continuous gravity erection system to satisfy verticality requirements in the terminal area because of the potential for more maneuvering and shorter periods of level flight prior to landing.

INS offers significant benefits in terms of performance, flexibility and safety. Safety is enhanced primarily in the terminal area, not only as described above for Category III operations, but for any IFR conditions, particularly at ill equipped airports. Flexibility is derived from the fact that INS represents a completely self-contained navigator which can function accurately, independent of any external navigation aids. The INS also offers flight control management through its computer and smooth, accurate, coupled flight control performance freeing the flight crew for other critical flight duties. The safety features are particularly important because a significant proportion of flight accidents occur in the terminal area when aircraft wander from the prescribed flight path. STOL aircraft operating from both the small, ill equipped airports and the high density hubs should find the flexibility offered by INS particularly attractive.

Strapdown systems offer a significant reduction in price and reliability. However, a conventionally configured strapdown system will still suffer many of the drawbacks of gimballed systems. The line replaceable unit will still be a complete inertial package (3 axes of gyros and accelerometers). Fail operational capability will still require three complete systems, thereby reducing the reliability of the fail operational condition by a factor of three over the reliability of a single system. A single system will still likely be at least a factor of two more expensive than a non-redundant set of instruments that could be replaced. In addition, strapdown systems will not have the reversionary attitude mode available when the computer fails. Several INS manufacturers are currently developing strapdown systems. All of these reflect conventional configurations with a price goal of $35K-$50K.

An integrated redundant strapdown system such as that being developed by The Charles Stark Draper Laboratory for NASA/Ames can be a real breakthrough for commercial INS making them cost effective for short-haul airline use. The primary features of such a system which could make it particularly attractive are:

(1) A high level of redundancy with a reduced level of duplication

(2) Reliable fault isolation reducing the probability of unverified removals (approximately 40 percent of present removals are unverified)

(3) On-line correction for stable bias shifts normally requiring a system removal

(4) Line replaceable components (gyros and accelerometers) rather than complete systems.

Items 2, 3, and 4 are generally very difficult or impossible to achieve with conventional nonredundant systems because of the inability to reliably detect and isolate component failures.

Several technological advances and demonstrations will be required before manufacturers and the airlines will be willing to risk an investment in an integrated redundant system. A program to develop and demonstrate such a system should include the following steps.

(1) A demonstration of adequate performance in both the normal and fault degraded modes. A demonstration utilizing a STOL vehicle and representative STOL profiles is particularly attractive because the greater rotational motion (roll, pitch, and yaw) will exercise the system in an environment in which strapdown is usually considered least suited. Performance should be evaluated, not just from the ability to navigate, but also from the ability to provide acceptable attitude information.

(2) A test of the fault isolation and on-line correction capabilities along with an analysis of the reliability of these techniques.

(3) Demonstration of line replaceable components.

(4) A cost analysis to show whether such a system could be significantly more cost effective than a dual conventionally configured strapdown system. It is important that this comparison be made to assure that the integrated system could be sold in sufficient quantity to take advantage of large production savings and to amortize development costs. It will have to be attractive to the airline desiring only dual redundancy as well as those requiring triple or fail-operational status.

(5) A reliability and failure mode analysis designed to show that the fail-operational requirements of a Category III Autoland system can be satisfied with an integrated system. It is one thing to show that a system can operate successfully in a degraded mode and that a high degree of operational reliability is achieved with a redundant system, but is quite another matter to convince the manufacturers, airlines, and certification authorities that the required statistical level of safety is achieved with redundancy in a single box. It should be noted that, although the arguments for the integrated system have not hinged on Category III, an aircraft manufacturer or airline would be reluctant to consider such a system unless it was compatible or could be made compatible (without duplication) with Category III requirements.

In addition, a flight test program of the SIRU system can be used to determine the adequacy of conventional vertical gyros to satisfy the autoland requirement for STOL aircraft.

EXAMINATION OF STOL OPERATING EXPERIMENTS

The purpose of this task was to examine the STOL Operating Experiments from the viewpoint of an airline or aircraft manufacturer, to determine the ability of the experiments to provide data and technology needed by these groups. As one part of this task, copies of the Experiment Plan (Reference 7) were sent to several members of industry for their comments. The responses received have been sent to NASA/Ames Research Center. The Experiment Plan provided the basis for examination of the proposed experiments.

The objectives of the STOL Operating Experiments are taken directly from the Experiment Plan:

> "...NASA and Ames Research Center in accordance with their mission in aeronautics propose to define and contribute to the technology development required to enable STOL transportation to become operational."
>
> "A STOL transportation system consists of the aircraft and related systems, navigation aids and data link, air traffic control, and operational constraints such as environment, customer, mission, etc. Ames Research Center is concerned primarily with the aircraft and related systems, but must consider this a part of the over-all STOL system and not as an isolated concept to properly investigate aircraft system performance, stability, control, etc."
>
> "The experiments will assist in establishing a data base for development of design criteria and operational procedures for STOL aircraft and related systems."

The Experiment Plan is much too general in nature for a detailed critique beyond that expressed in the industry responses of Appendix C. The Plan is clearly responsive to the stated objectives and will influence airline cost and manufacturer design to the extent that it can provide data for optimization of in-flight performance with minimum hardware complexity. The airlines, aircraft manufacturers, and avionics manufacturers will almost certainly rely heavily on the data provided for advanced design concepts. However, it is also clear that the avionics complexity required to optimize STOL performance in the future, congested ATC environment will greatly exceed the complexity of equipment aboard present short-haul aircraft. This increased complexity will almost certainly increase maintainability costs. The amount of this increase, if any, will depend to a great extent on the reliability/maintainability technology available at the time.

The hazards of increasing system complexity without improving the maintainability characteristics were evident in the simulation results of Table 8, Page 35. Those results were obtained assuming conventional analog technology to achieve the Category III capability.

The following excerpts from an airline report depict the maintainability problems that the airlines have been experiencing.

> "Maintenance expense...comprises about 25 percent of direct operating costs"

> "Maintenance efforts...are often ineffective in detecting, preventing, and correcting failures because of the inability to detect incipient failures by means of...functional tests and because of the inability to locate faults after a failure has been recognized"

> "52 percent of the (autopilot) components replaced on an unscheduled basis during maintenance checks did not eliminate the pilot's complaint"

> "Disregarding downtime..., the cost of maintenance over the 15 year life of a jet transport can be expected to total about 2 times its original cost. (Certain system and component costs can be expected to total 10 to 100 times their original cost.)"

It would seem that some of these problems would be relieved with newer, more advanced aircraft. However, the following excerpt from the November 12, 1973, issue of Aviation Week and Space Technology implies that the reverse is true.

> "Dispatch reliability of the three primary wide-body aircraft is leveling off at a standard below that of smaller aircraft such as the Boeing 727 and the McDonnell Douglas DC-9 at the same point in their operations. Frank Borman, Eastern's senior vice president-operations group, in noting this commented that airlines should have expected it despite

manufacturer forecasts because of the complexity of the larger aircraft. Poorer reliability problem is compounded because of the larger number of passengers involved on the Boeing 747s, McDonnell Douglas DC-10s and the Lockheed L-1011s."

The adverse maintainability implications of increased complexity can be neutralized with parallel technology developments in the areas of reliability and maintainability. Without these developments, airlines and aircraft manfuacturers will be reluctant to implement the new avionics techniques developed through the Experiment Program. Specifically, a reliability/maintainability technology program should be aimed at achieving the following objectives.

(1) Longer effective system MTBF. This does not necessarily imply use of higher reliability components, but can also be achieved with more integrated redundancy (as opposed to redundancy by black box duplication), use of reconfigurable or self organizing digital computer techniques, etc.

(2) Elimination of unverified removals which presently represent as much as half of all removals.

(3) Shorter mean maintenance delays through techniques for rapid test and replacement.

(4) Reduced spares costs.

There does not appear to be any development activity, either within the Experiment Plan or in other STOL avionics programs, aimed at achieving these objectives.

REFERENCES

(1) Hitt, E. F., et al, "Effectiveness Evaluation of STOL Transport Operations", Battelle, Columbus Laboratories, NASA Contract No. NAS2-6889 (February 20, 1973).

(2) Duning, K. E., et al, "Curved Approach Path Study", Collins Radio Company, DOT/FAA Report No. FAA-RD-72-143 (April, 1973).

(3) "Effectiveness Evaluation of STOL Transport Operations", Battelle, Columbus Laboratories", NASA Contract No. NAS2-6889 (February, 1973).

(4) "Engineering and Development Program Plan for the Upgraded Third Generation ATC System", MITRE Corporation, FAA Report No. FAA ED-01-1A (August, 1972).

(5) "Fourth Generation Air Traffic Control Study", Autonetics Avionics and Sensors Division, North American Rockwell Corporation, Department of Transportation Report No. DOT-TSC-304-1 (June, 1972).

(6) "Models for Runway Capacity Analysis", MITRE Corporation, Report No. MTR-4102 Rev. 2 (December, 1972).

(7) "STOL Operating Experiments", Final Report of the Flight Experiments Committee of the Joint DOT/NASA STOL Operating Experiments Steering Group (July 21, 1972).

APPENDIX A

LOW VISIBILITY WEATHER MODEL

APPENDIX A

LOW VISIBILITY WEATHER MODEL

The data required to model the visibility-ceiling conditions in the terminal area in terms of VFR, Category I, Category II, and Category III include:

1. Probability of occurrence of each condition
2. The duration or correlation time of each condition once it occurs
3. The logic which defines the transition between conditions.

Data have been collected to model the conditions at San Jose Municipal, Orange County and Sacramento Executive. Each type of data and the resultant model are discussed below.

Visibility-Ceiling Probability of Occurrence

Under Task 7.1 of the contract, weather data in the vicinity of San Jose Municipal, Sacramento Executive and Orange County were obtained from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration. The actual data are from McClellan AFB near Sacramento, Moffett Naval Air Station near San Jose and Santa Ana (Marine Corps Air Field) near Orange County. Following is a discussion of the low visibility data which were obtained.

Visibility data are presented as a bivariate percentage frequency distribution of ceiling versus visibility. Table A-1 is typical of the data. Note that in this case the data are for Santa Ana MCAS and were gathered during the period 1946-1947, 1952, 1954-1969. The data are for February covering the three hourly observations from 0600-0800. All data âre from hourly observations and are summarized as follows:

1. Annual - all years and all hours combined
2. By month - all years and all hours combined
3. By month - by standard 3-hour groups.

The standard 3-hours group summary was not available for McClellan AFB.

Table A-2 is a repeat of Table A-1 except that the boundaries on the landing weather categories have been indicated. The upper limit on Category I or IFR weather is 1000 feet ceiling and 3 miles visibility.

CEILING VERSUS VISIBILITY

93114 (STATION) — SANTA ANA, CALIFORNIA MCAS (STATION NAME) — 46-47,52,54-69 (YEARS) — FEB (MONTH)

PERCENTAGE FREQUENCY OF OCCURRENCE
(FROM HOURLY OBSERVATIONS)

0600-0800 (HOURS (L.S.T.))

CEILING (FEET)	VISIBILITY (STATUTE MILES) ≥ 10	≥ 6	≥ 5	≥ 4	≥ 3	≥ 2½	≥ 2	≥ 1½	≥ 1¼	≥ 1	≥ ¾	≥ ⅝	≥ ½	≥ 5/16	≥ ¼	≥ 0
NO CEILING	37.9	45.0	48.2	50.2	52.7	53.1	53.8	54.4	54.5	55.4	56.4	56.5	56.9	56.9	57.3	57.5
≥ 20000	39.7	48.2	50.6	53.0	55.6	56.1	57.2	57.8	57.9	59.1	60.1	60.2	60.6	60.6	61.1	61.2
≥ 18000	39.7	48.2	50.6	53.0	55.6	56.1	57.2	57.8	57.9	59.1	60.1	60.2	60.6	60.6	61.1	61.2
≥ 16000	39.9	48.3	50.8	53.1	55.8	56.3	57.4	58.1	58.1	59.3	60.3	60.4	60.8	60.8	61.3	61.5
≥ 14000	40.4	48.8	51.4	53.8	56.8	57.3	58.4	59.1	59.2	60.4	61.5	61.5	61.9	61.9	62.5	62.6
≥ 12000	41.0	49.4	52.1	54.5	57.5	58.0	59.2	59.9	60.0	61.3	62.5	62.5	63.0	63.0	63.5	63.7
≥ 10000	42.1	50.6	53.4	55.9	58.8	59.4	60.6	61.2	61.4	62.7	63.8	63.9	64.4	64.4	64.9	65.0
≥ 9000	42.5	51.0	53.8	56.2	59.2	59.7	60.9	61.6	61.8	63.1	64.2	64.3	64.7	64.7	65.3	65.4
≥ 8000	42.9	51.4	54.4	56.9	60.0	60.5	61.7	62.4	62.5	63.8	65.0	65.1	65.6	65.6	66.2	66.3
≥ 7000	43.2	51.9	55.0	57.4	60.5	61.0	62.2	62.9	63.1	64.4	65.6	65.6	66.2	66.2	66.7	66.8
≥ 6000	43.4	52.1	55.3	57.7	60.8	61.3	62.6	63.3	63.4	64.7	65.9	66.0	66.5	66.5	67.1	67.2
≥ 5000	44.3	53.4	56.8	59.2	62.3	62.8	64.1	64.8	65.0	66.2	67.5	67.5	68.1	68.1	68.6	68.7
≥ 4500	44.7	53.9	57.3	59.9	63.0	63.5	65.0	65.6	65.8	67.1	68.3	68.4	68.9	68.9	69.4	69.6
≥ 4000	45.6	55.1	58.7	61.3	64.4	65.0	66.4	67.1	67.2	68.5	69.8	69.9	70.5	70.5	71.0	71.2
≥ 3500	46.0	55.6	59.3	62.1	65.3	65.9	67.4	68.1	68.3	69.6	70.9	70.9	71.5	71.5	72.1	72.2
≥ 3000	47.3	57.5	61.8	64.6	67.9	68.5	70.1	70.8	71.0	72.3	73.6	73.7	74.3	74.3	74.8	75.0
≥ 2500	48.7	59.7	63.8	66.8	70.3	71.0	72.6	73.5	73.7	75.0	76.3	76.4	77.0	77.0	77.5	77.7
≥ 2000	50.1	62.3	66.6	69.9	73.6	74.7	76.4	77.4	77.6	79.0	80.2	80.3	80.9	80.9	81.5	81.7
≥ 1800	50.2	62.4	66.9	70.2	74.2	75.1	76.8	77.7	78.0	79.3	80.6	80.7	81.3	81.3	81.8	82.1
≥ 1500	50.9	64.0	69.3	72.9	77.0	78.2	80.2	81.2	81.4	82.9	84.2	84.3	84.9	84.9	85.4	85.6
≥ 1200	51.1	64.2	69.6	73.3	77.4	78.7	80.9	82.1	82.4	84.0	85.3	85.4	86.1	86.1	86.6	86.8
≥ 1000	51.5	65.0	70.5	74.3	78.7	80.2	82.7	84.0	84.3	85.9	87.3	87.4	88.1	88.1	88.6	88.9
≥ 900	51.5	65.0	70.5	74.3	78.8	80.2	82.7	84.1	84.4	86.0	87.4	87.5	88.2	88.2	88.7	89.0
≥ 800	51.6	65.1	70.6	74.4	79.2	80.8	83.0	85.2	85.6	87.3	88.7	88.9	89.6	89.6	90.1	90.3
≥ 700	51.6	65.1	70.6	74.4	79.3	80.9	83.8	85.5	85.9	87.6	89.1	89.3	90.0	90.0	90.5	90.8
≥ 600	51.6	65.1	70.6	74.6	79.6	81.2	84.0	85.8	86.3	88.0	89.6	89.9	90.7	90.7	91.2	91.5
≥ 500	51.6	65.3	71.1	75.1	80.2	81.8	84.7	86.5	87.1	88.8	90.8	91.0	91.5	91.8	92.4	92.6
≥ 400	51.6	65.3	71.1	75.1	80.2	81.8	84.7	86.7	87.2	89.1	91.1	91.3	92.1	92.1	92.7	93.0
≥ 300	51.6	65.3	71.2	75.2	80.3	81.9	84.8	86.8	87.3	89.3	91.3	91.5	92.4	92.5	93.1	93.5
≥ 200	51.6	65.3	71.2	75.2	80.3	81.9	84.8	86.8	87.3	89.3	91.5	91.6	92.5	93.0	93.6	95.0
≥ 100	51.6	65.3	71.2	75.2	80.3	81.9	84.8	86.8	87.3	89.3	91.5	91.6	92.9	93.1	94.2	96.5
≥ 0	51.6	65.3	71.2	75.2	80.3	81.9	84.8	86.8	87.3	89.3	91.5	91.6	93.0	93.3	94.5	100.0

TOTAL NUMBER OF OBSERVATIONS 1321

NAVWEASERVCOM

5703 CEILING VERSUS VISIBILITY JAN 68

TABLE A-1. REPRESENTATIVE CEILING VERSUS VISIBILITY TABLE

CEILING VERSUS VISIBILITY

93114 SANTA ANA, CALIFORNIA MCAS (STATION NAME) — 46-47,52,54-69 (YEARS) — FEB (MONTH)

PERCENTAGE FREQUENCY OF OCCURRENCE
(FROM HOURLY OBSERVATIONS)

0600-0800 (HOURS (L.S.T.))

CEILING (FEET)	VISIBILITY (STATUTE MILES) ≥ 10	≥ 6	≥ 5	≥ 4	≥ 3	≥ 2½	≥ 2	≥ 1½	≥ 1¼	≥ 1	≥ ¾	≥ ⅝	≥ ½	≥ 5/16	≥ ¼	≥ 0	
NO CEILING	37.9	45.0	48.2	50.2	52.7	53.1	53.8	54.4	54.5	55.4	56.4	56.5	56.9	56.9	57.3	57.5	
≥ 20000	39.7	48.2	50.6	53.0	55.6	56.1	57.2	57.8	57.9	59.1	60.1	60.2	60.6	60.6	61.1	61.2	
≥ 18000	39.7	48.2	50.6	53.0	55.6	56.1	57.2	57.8	57.9	59.1	60.1	60.2	60.6	60.6	61.1	61.2	
≥ 16000	39.9	48.3	50.8	53.1	55.8	56.3	57.4	58.1	58.1	59.3	60.3	60.4	60.8	60.8	61.3	61.5	
≥ 14000	40.4	48.8	51.4	53.8	56.8	57.3	58.4	59.1	59.2	60.4	61.5	61.5	61.9	61.9	62.5	62.6	
≥ 12000	41.0	49.4	52.1	54.5	57.5	58.0	59.2	59.9	60.0	61.3	62.5	62.5	63.0	63.0	63.5	63.7	
≥ 10000	42.1	50.6	53.4	55.9	58.8	59.4	60.6	61.2	61.4	62.7	63.8	63.9	64.4	64.4	64.9	65.0	
≥ 9000	42.5	51.0	53.8	56.3	59.2	59.7	60.9	61.6	61.8	63.1	64.2	64.3	64.7	64.7	65.3	65.4	
≥ 8000	42.9	51.4	54.4	56.9	60.0	60.5	61.7	62.4	62.5	63.8	65.0	65.1	65.6	65.6	66.2	66.3	
≥ 7000	43.2	51.9	55.0	57.4	60.5	61.0	62.2	62.9	63.1	64.4	65.6	65.6	66.2	66.2	66.7	66.8	
≥ 6000	43.4	52.1	55.3	57.7	60.8	61.3	62.6	63.3	63.4	64.7	65.9	66.0	66.5	66.5	67.1	67.2	
≥ 5000	44.3	53.4	56.8	59.2	62.3	62.8	64.1	64.9	65.0	66.2	67.5	67.5	68.1	68.1	68.6	68.7	
≥ 4500	44.7	53.9	57.3	59.9	63.0	63.5	65.0	65.6	65.8	67.1	68.3	68.4	68.9	68.9	69.4	69.6	
≥ 4000	45.6	55.1	58.7	61.3	64.4	65.0	66.4	67.1	67.2	68.5	69.8	69.9	70.5	70.5	71.0	71.2	
≥ 3500	46.0	55.6	59.3	62.1	65.3	65.9	67.4	68.1	68.2	69.6	70.9	70.9	71.5	71.5	72.1	72.2	
≥ 3000	47.3	57.8	61.8	64.6	67.9	68.5	70.1	70.8	71.0	72.3	73.6	73.7	74.3	74.3	74.8	75.0	
≥ 2500	48.7	59.7	63.8	66.8	70.3	71.0	72.6	73.5	73.7	75.0	76.3	76.4	77.0	77.0	77.3	77.7	
≥ 2000	50.1	62.3	66.6	69.9	73.8	74.7	76.4	77.4	77.6	79.0	80.2	80.3	80.9	80.9	81.5	81.7	
≥ 1800	50.2	62.4	66.9	70.2	74.2	75.1	76.8	77.7	78.0	79.3	80.6	80.7	81.3	81.3	81.8	82.1	
≥ 1500	50.9	64.0	69.3	72.9	77.0	78.2	80.2	81.2	81.4	82.9	84.2	84.3	84.9	84.9	85.4	85.6	
≥ 1200	51.1	64.2	69.6	73.3	77.4	78.7	80.9	82.1	82.4	84.0	85.3	85.4	86.1	86.1	86.6	86.8	
≥ 1000	51.5	65.0	70.5	74.3	78.7	80.2	82.7	84.0	84.3	85.9	87.3	87.4	88.1	88.1	88.6	88.9	
≥ 900	51.5	65.0	70.5	74.3	78.8	80.2	82.7	84.1	84.4	86.0	87.4	87.5	88.2	88.2	88.7	89.0	
≥ 800	51.6	65.1	70.6	74.4	79.2	80.8	83.5	85.2	85.6	87.3	88.7	88.9	89.6	89.6	90.1	90.3	
≥ 700	51.6	65.1	70.6	74.4	79.3	80.9	83.8	85.5	85.9	87.6	89.1	89.3	90.0	90.0	90.5	90.8	Cat. I
≥ 600	51.6	65.1	70.6	74.6	79.6	81.2	84.0	85.8	86.3	88.0	89.8	89.9	90.7	90.7	91.2	91.5	
≥ 500	51.6	65.3	71.1	75.1	80.2	81.8	84.7	86.5	87.1	88.8	90.8	91.0	91.9	91.9	92.4	92.6	
≥ 400	51.6	65.3	71.1	75.1	80.2	81.8	84.7	86.7	87.2	89.1	91.1	91.3	92.1	92.1	92.7	93.0	
≥ 300	51.6	65.3	71.2	75.2	80.3	81.9	84.8	86.8	87.3	89.3	91.3	91.5	92.4	92.5	93.1	93.5	
≥ 200	51.6	65.3	71.2	75.2	80.3	81.9	84.8	86.8	87.3	89.3	91.5	91.6	92.8	93.0	93.8	95.0	Cat. II
≥ 100	51.6	65.3	71.2	75.2	80.3	81.9	84.8	86.8	87.3	89.3	91.5	91.6	92.9	93.1	94.2	96.5	
≥ 0	51.6	65.3	71.2	75.2	80.3	81.9	84.8	86.8	87.3	89.3	91.5	91.6	93.0	93.3	94.5	100.0	Cat. III

TOTAL NUMBER OF OBSERVATIONS 1321

5703 CEILING VERSUS VISIBILITY JAN 68

NAVWEASERVCOM

TABLE A-2. CEILING VERSUS VISIBILITY TABLE SHOWING BOUNDS OF WEATHER CATEGORIES

For this case the probability of Category I <u>or worse</u> weather conditions is 100% - 78.7% = 21.3%. Category I weather conditions extend down to 200 feet ceiling and 2400 feet visibility. Thus, the probability of Category II <u>or worse</u> conditions is approximately 100% - 92.8% = 7.2% Category II conditions extend down to 100 feet ceiling and 1200 feet visibility. Thus, the probability of Category III weather for this case is approximately 100% - 94.2% = 5.8%. The probability of Category II conditions is the probability of Category II <u>or worse</u> minus the probability of Category III conditions. Thus, for this case the probability of Category II conditions is

P(Cat. II) = P(Cat. II or worse) - P(Cat. III) = 7.2% - 5.8% = 1.4%.

Similarly, the probability of category I conditions is

P(Cat. I) = P(Cat. I or worse) - P(Cat. II or worse) = 21.3% - 7.2% = 14.1%.

Figures A-1 through A-12 show these probabilities for Moffett Field plotted as a function of three hour period for each month. Figures A-13 through A-24 show similar data for Santa Ana. Note in these figures that the weather is worst in the winter months of November through March. Figures A-25 and A-27 show the average conditions for these months at Moffett Field and Santa Ana respectively. Figures A-26 and A-28 show similar averages for the remainder of the year.

Figure A-29 shows the monthly average conditions for McClellan AFB. Hourly data were not available for this location.

Visibility-Ceiling Duration

Climatological summaries[1] supplied by the National Climatic Center give some data on the expected duration of Category II and III conditions. These data are presented in the form of the number of occurrences of a given duration during a ten-year period. Data are available for Los Angeles and Oakland which are closest geographically to the simulated scenario. The data for these airports are shown in Table A-3. Figure A-30 is a plot of the time of duration versus the percentage of the occurrences which are of greater than or equal duration. In other words, it presents duration time versus the probability of remaining in the present category. The following two assumptions are made based on a straight line fit of the data:

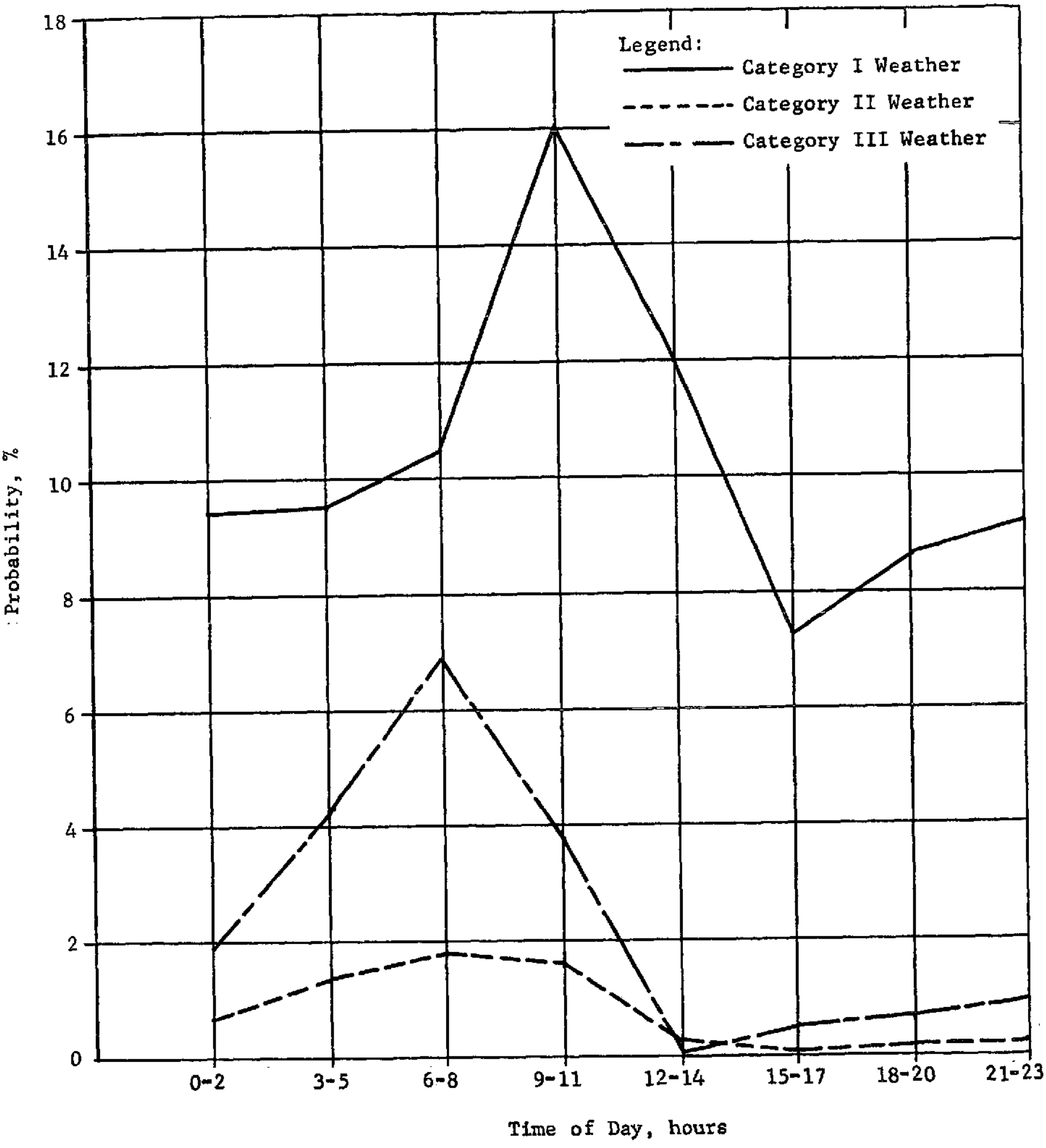


FIGURE A-1. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR JANUARY AT MOFFETT FIELD, CALIFORNIA

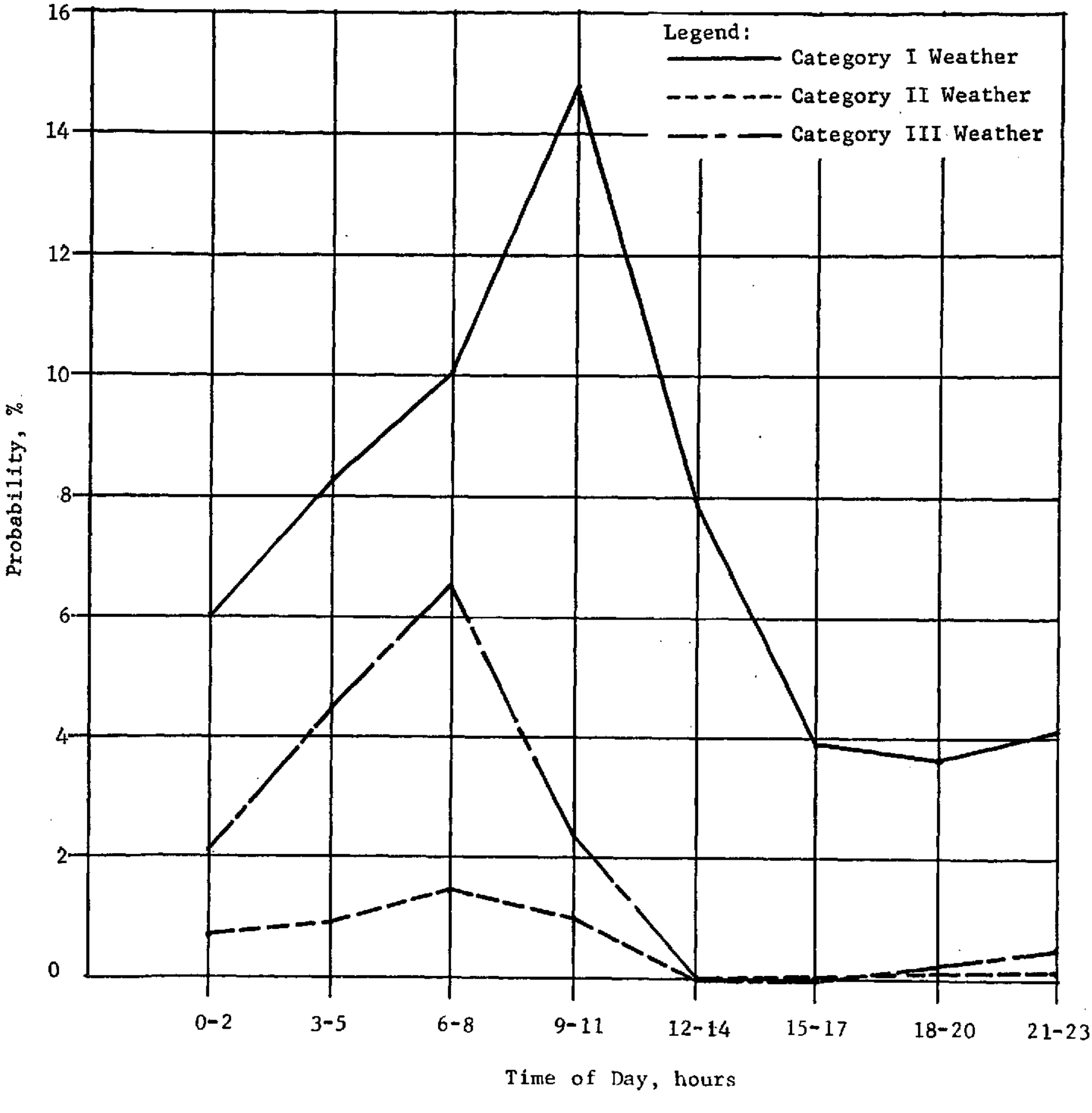


FIGURE A-2. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR FEBRUARY AT MOFFETT FIELD, CALIFORNIA

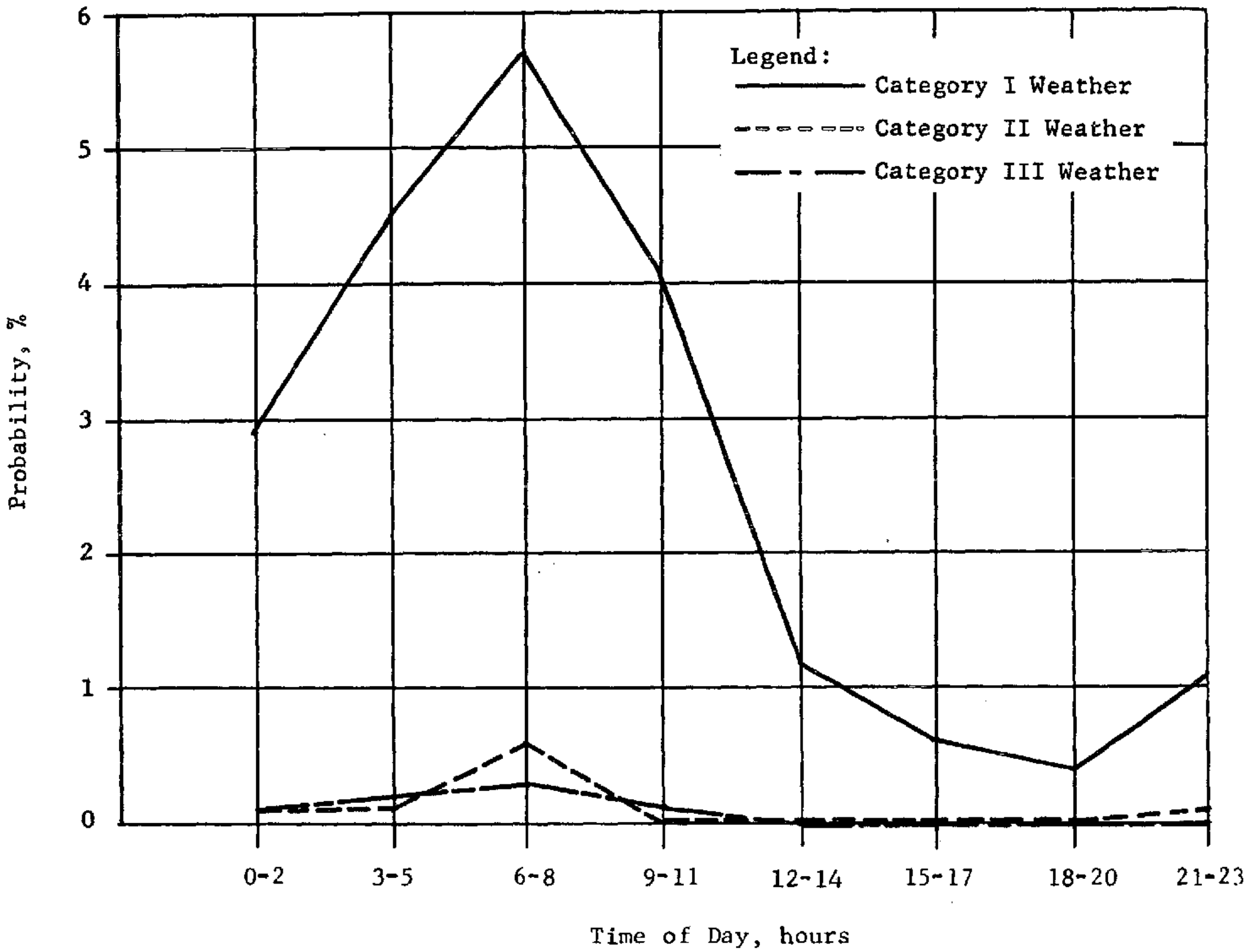


FIGURE A-3. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR MARCH AT MOFFETT FIELD, CALIFORNIA

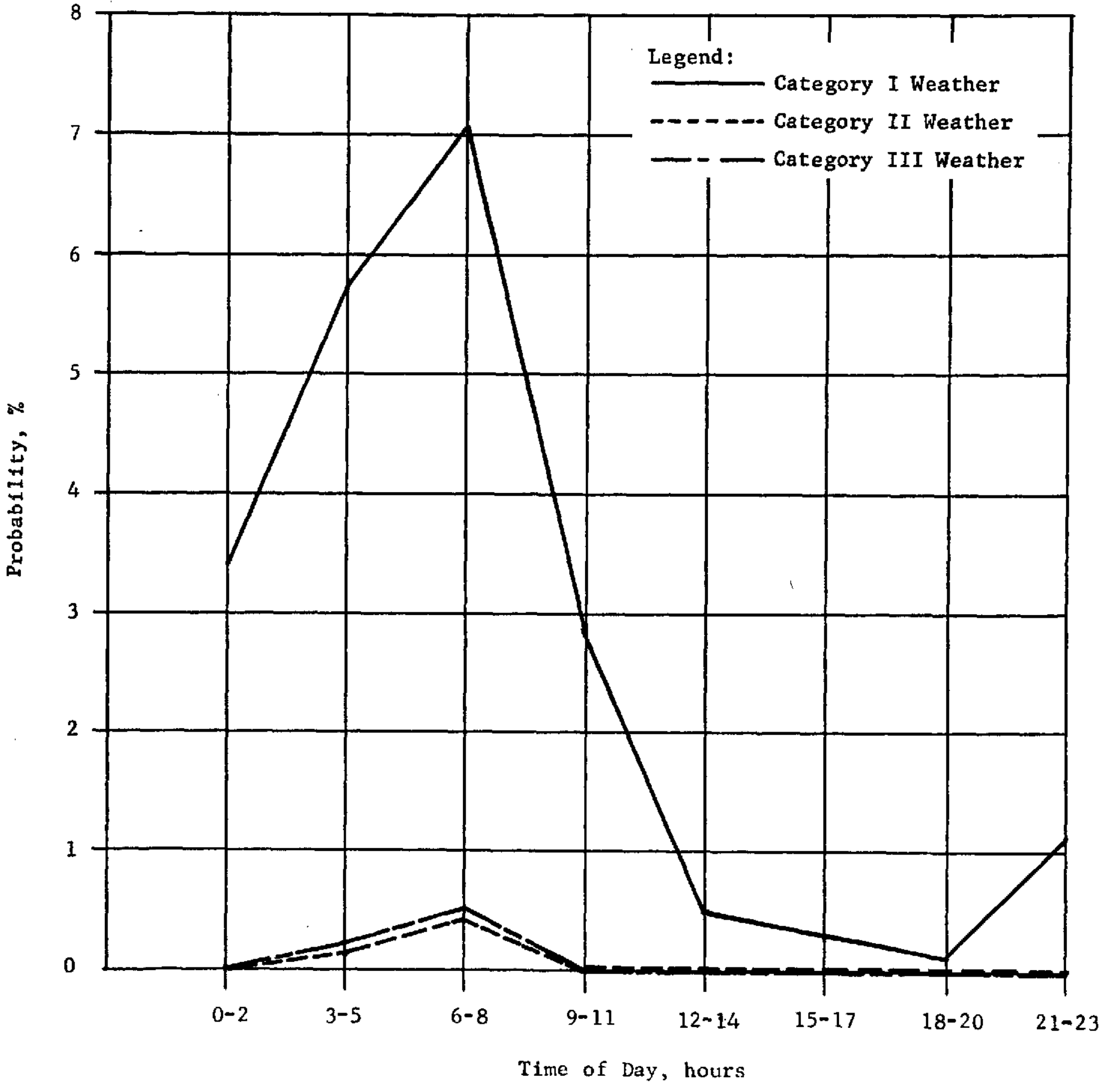


FIGURE A-4. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR APRIL AT MOFFETT FIELD, CALIFORNIA

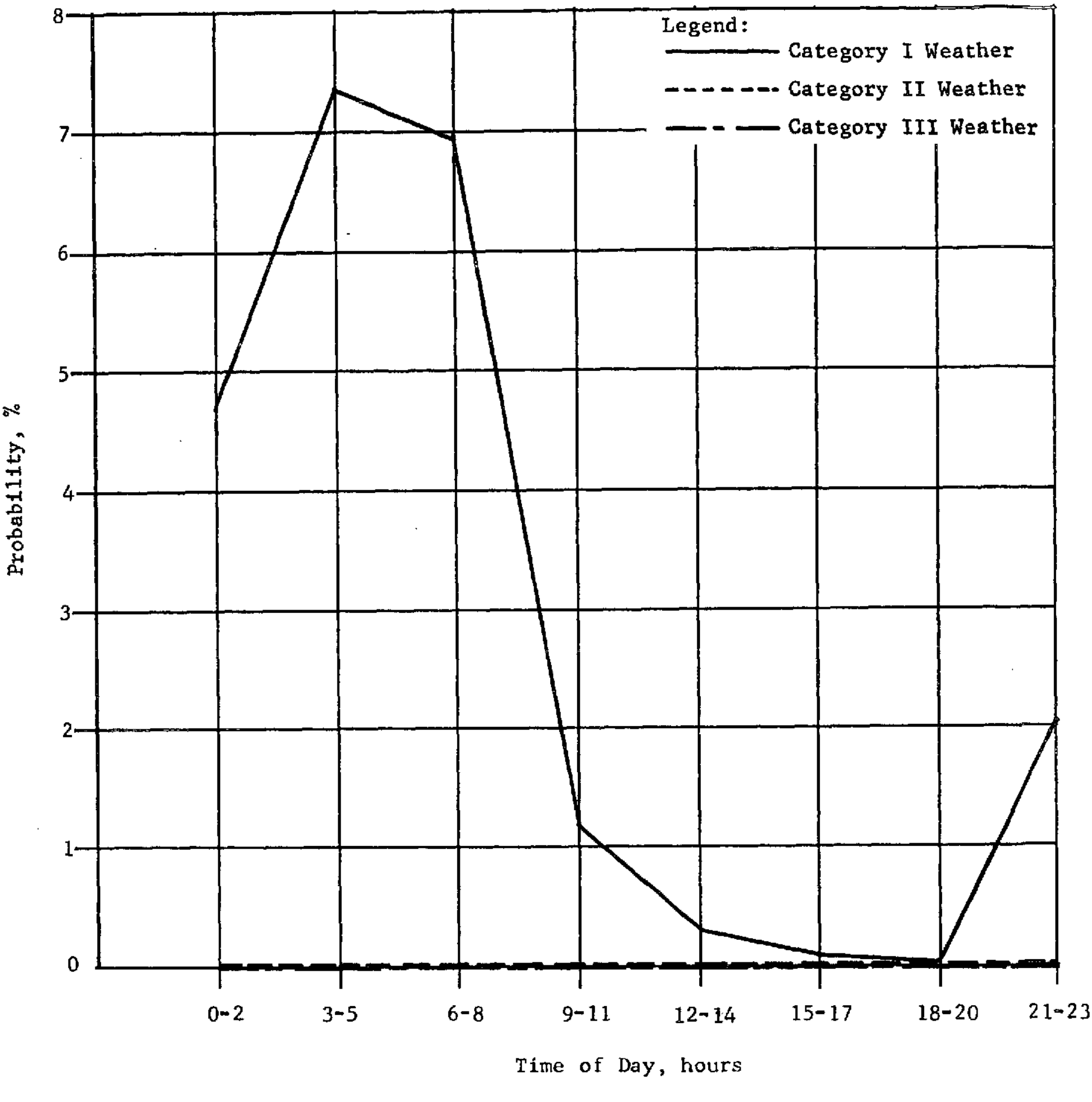


FIGURE A-5. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR MAY AT MOFFETT FIELD, CALIFORNIA

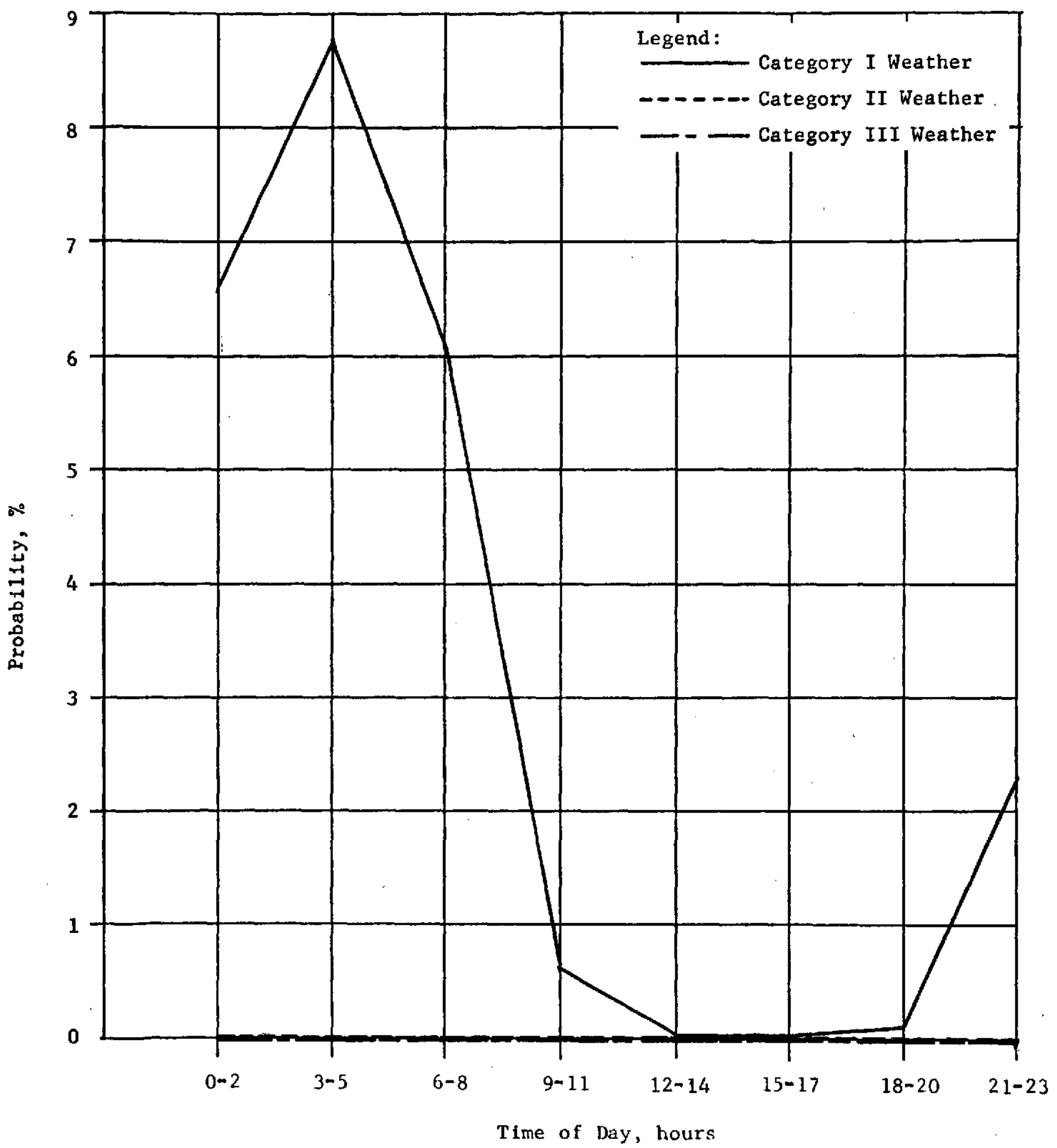


FIGURE A-6. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR JUNE AT MOFFETT FIELD, CALIFORNIA

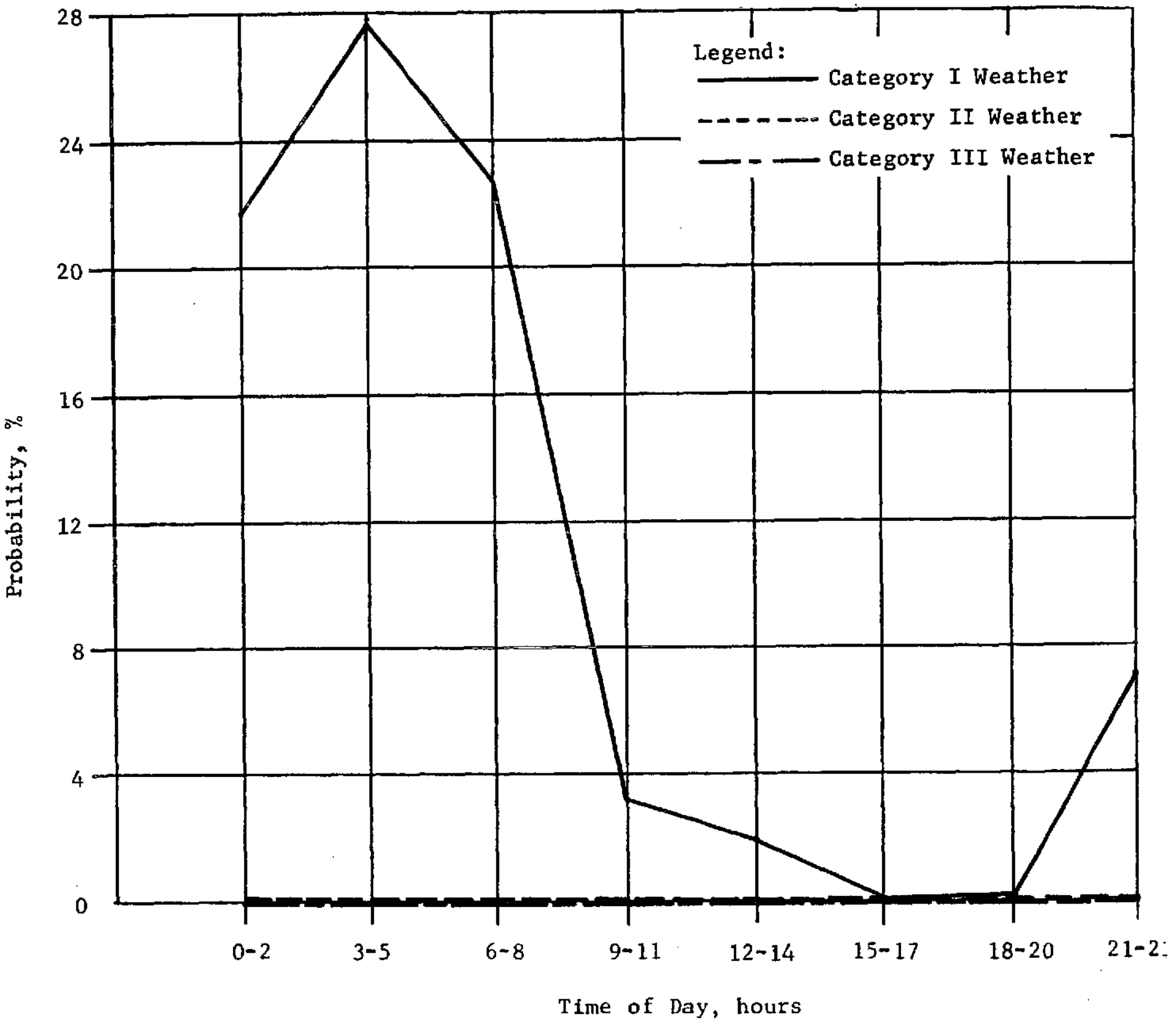


FIGURE A-7. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR JULY AT MOFFETT FIELD, CALIFORNIA

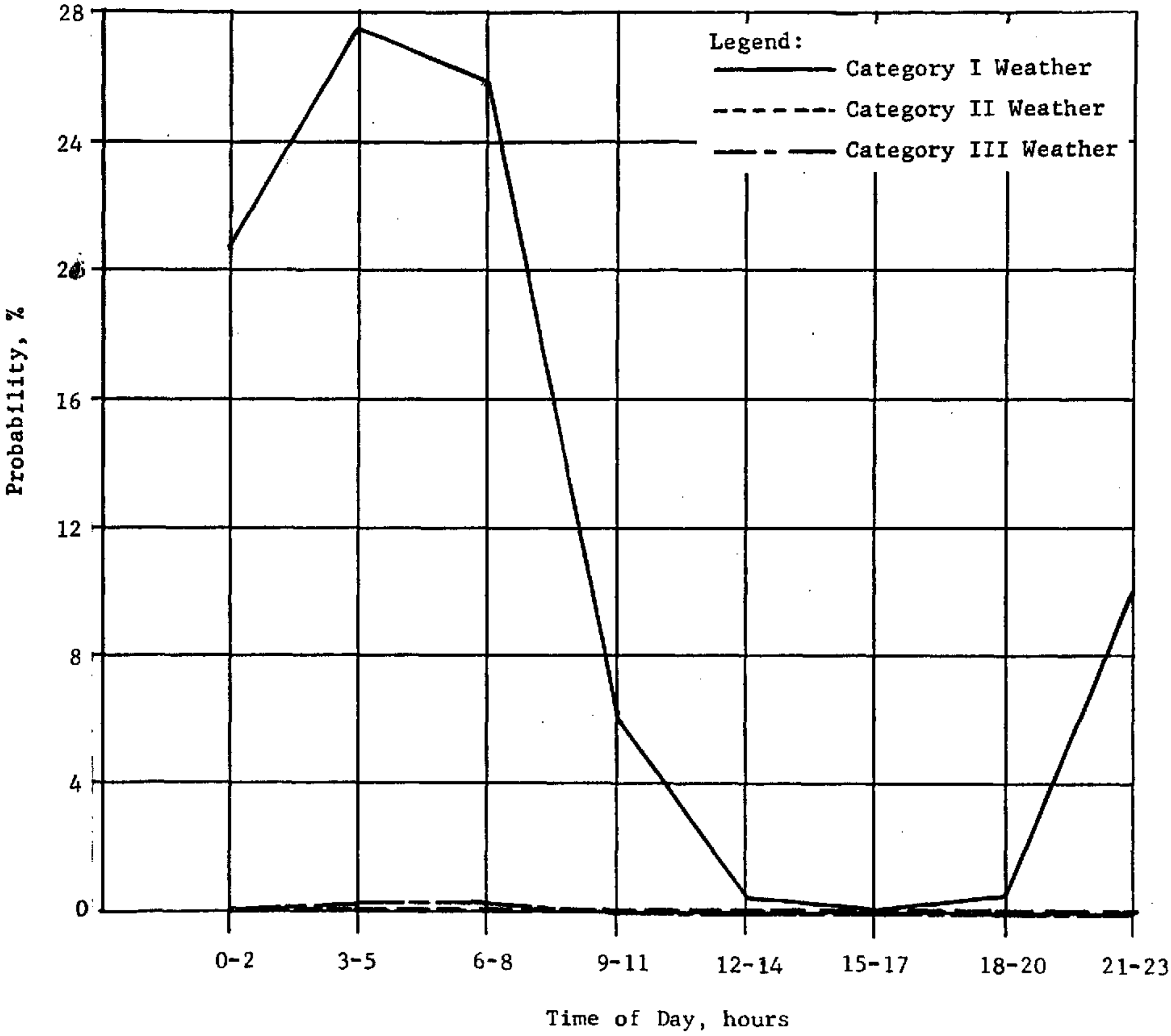


FIGURE A-8. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR AUGUST AT MOFFETT FIELD, CALIFORNIA

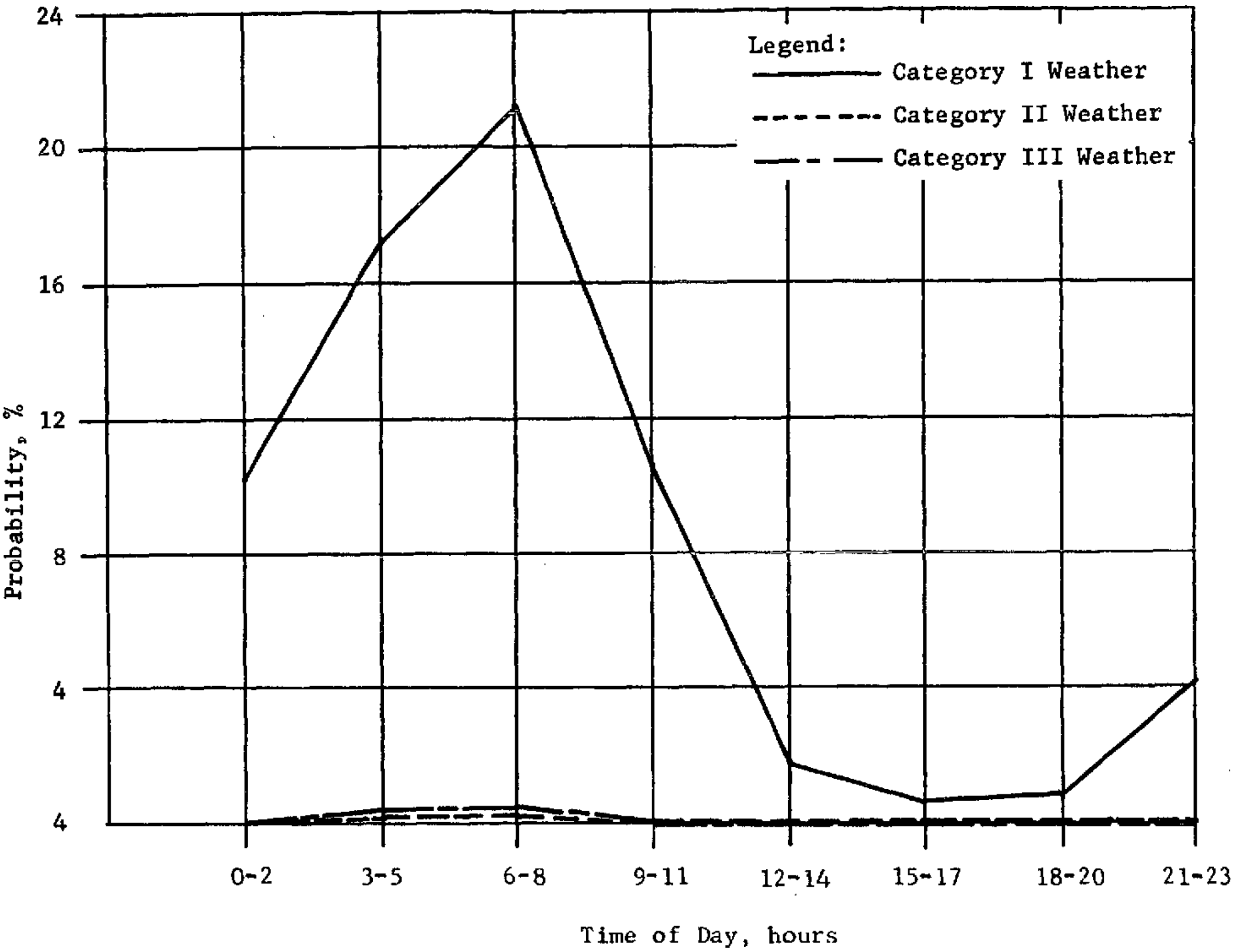


FIGURE A-9. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR SEPTEMBER AT MOFFETT FIELD, CALIFORNIA

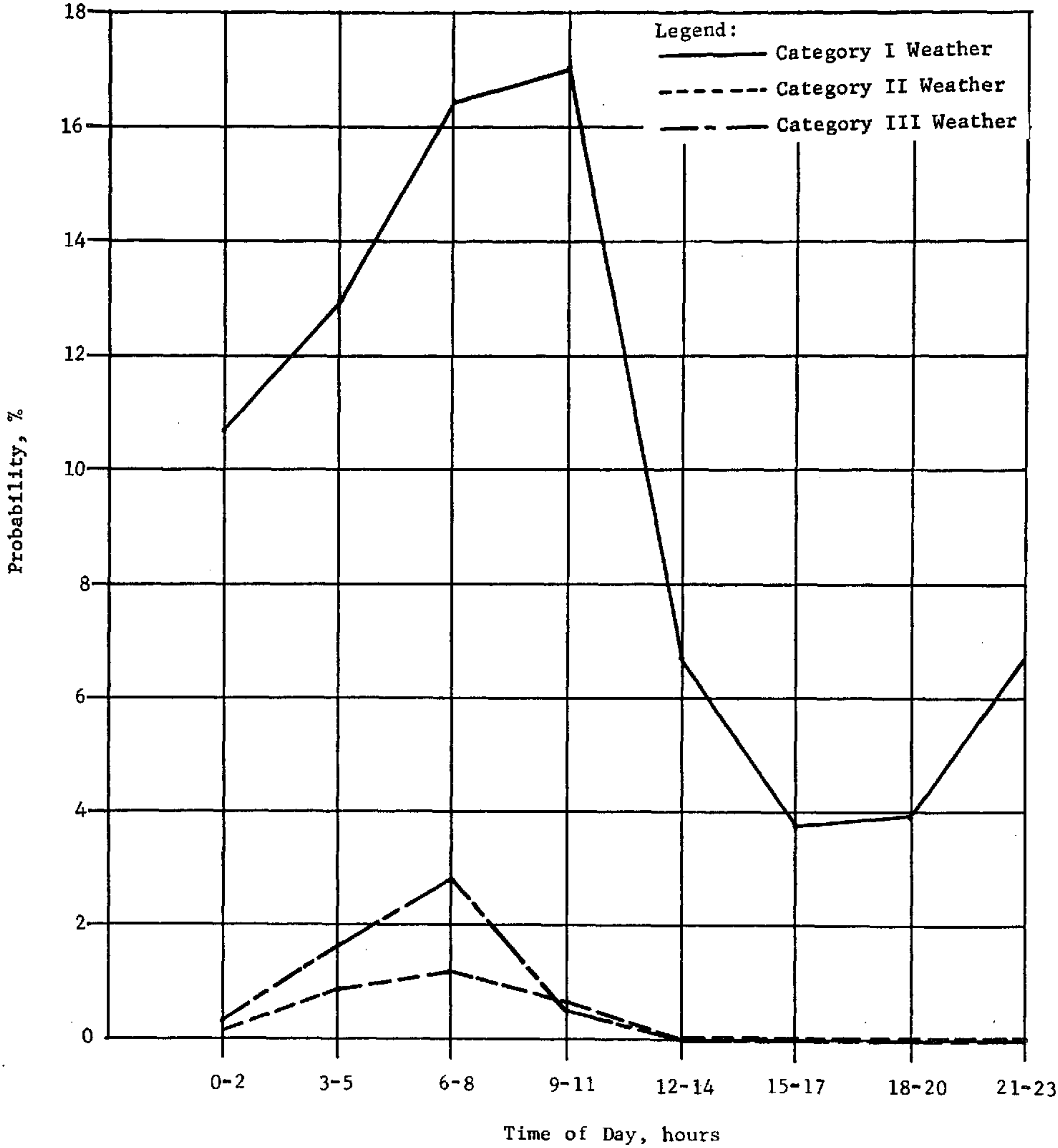


FIGURE A-10. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR OCTOBER AT MOFFETT FIELD, CALIFORNIA

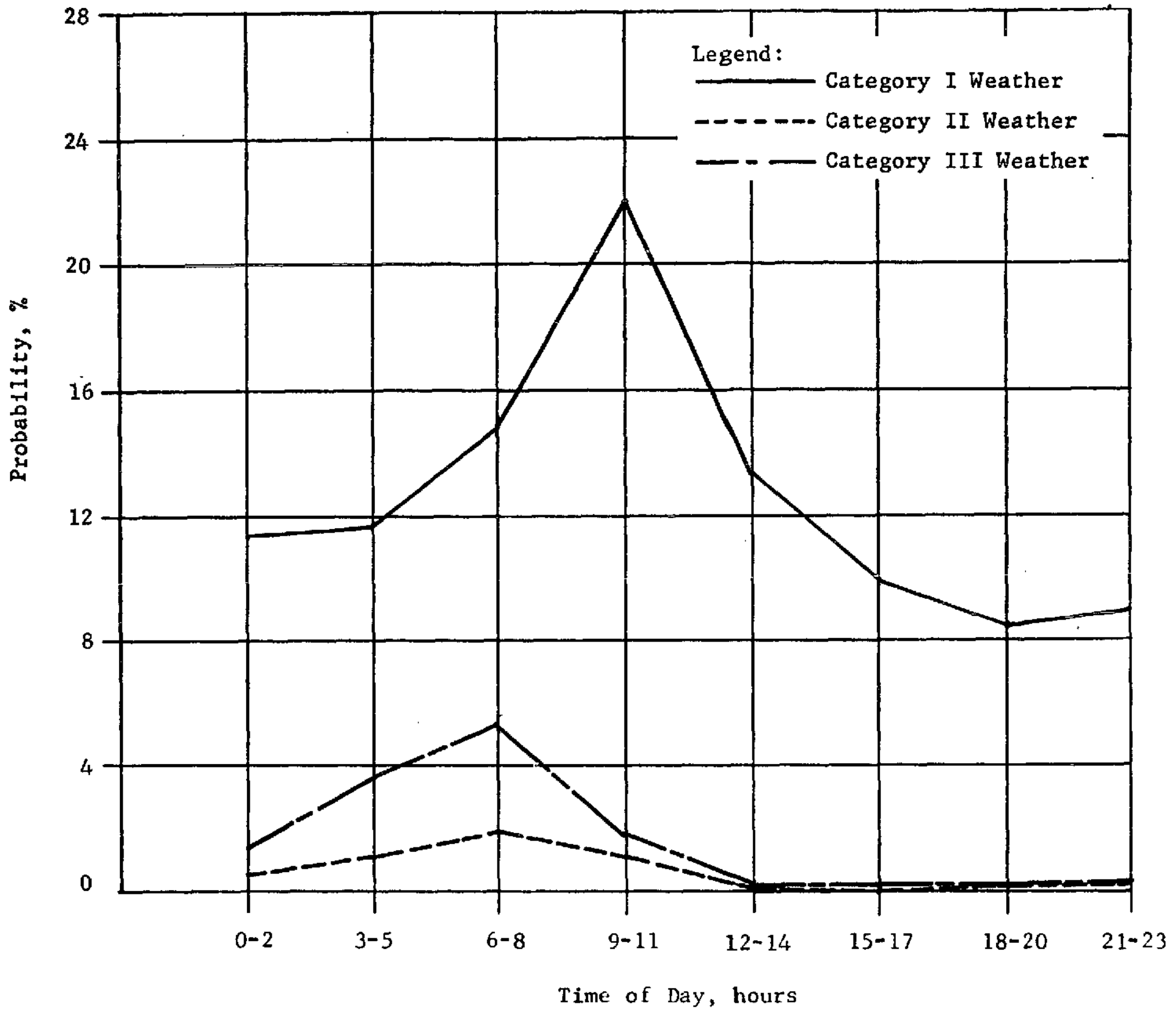


FIGURE A-11. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR NOVEMBER AT MOFFETT FIELD, CALIFORNIA

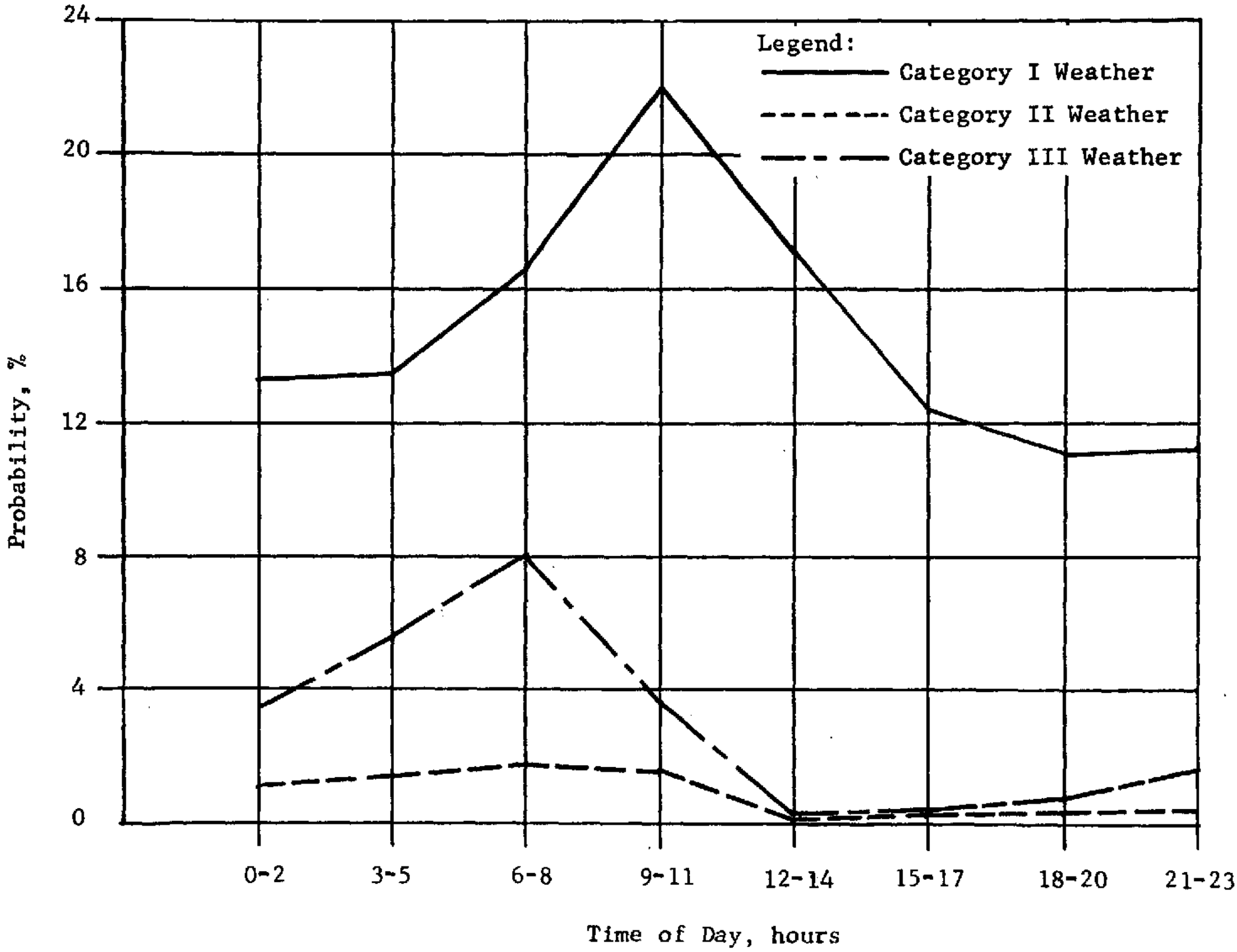


FIGURE A-12. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR DECEMBER AT MOFFETT FIELD, CALIFORNIA

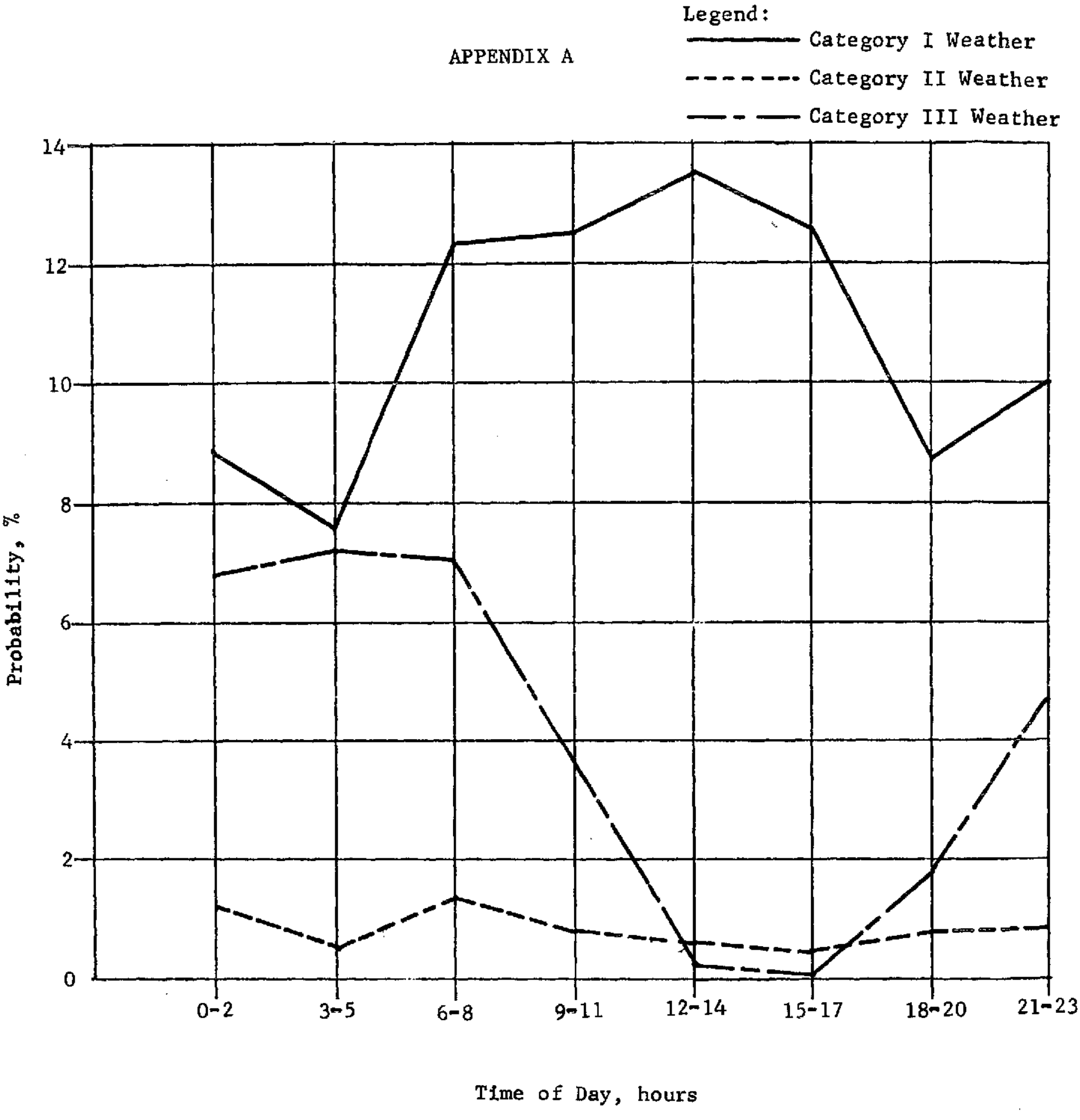


FIGURE A-13. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR JANUARY AT SANTA ANA, CALIFORNIA

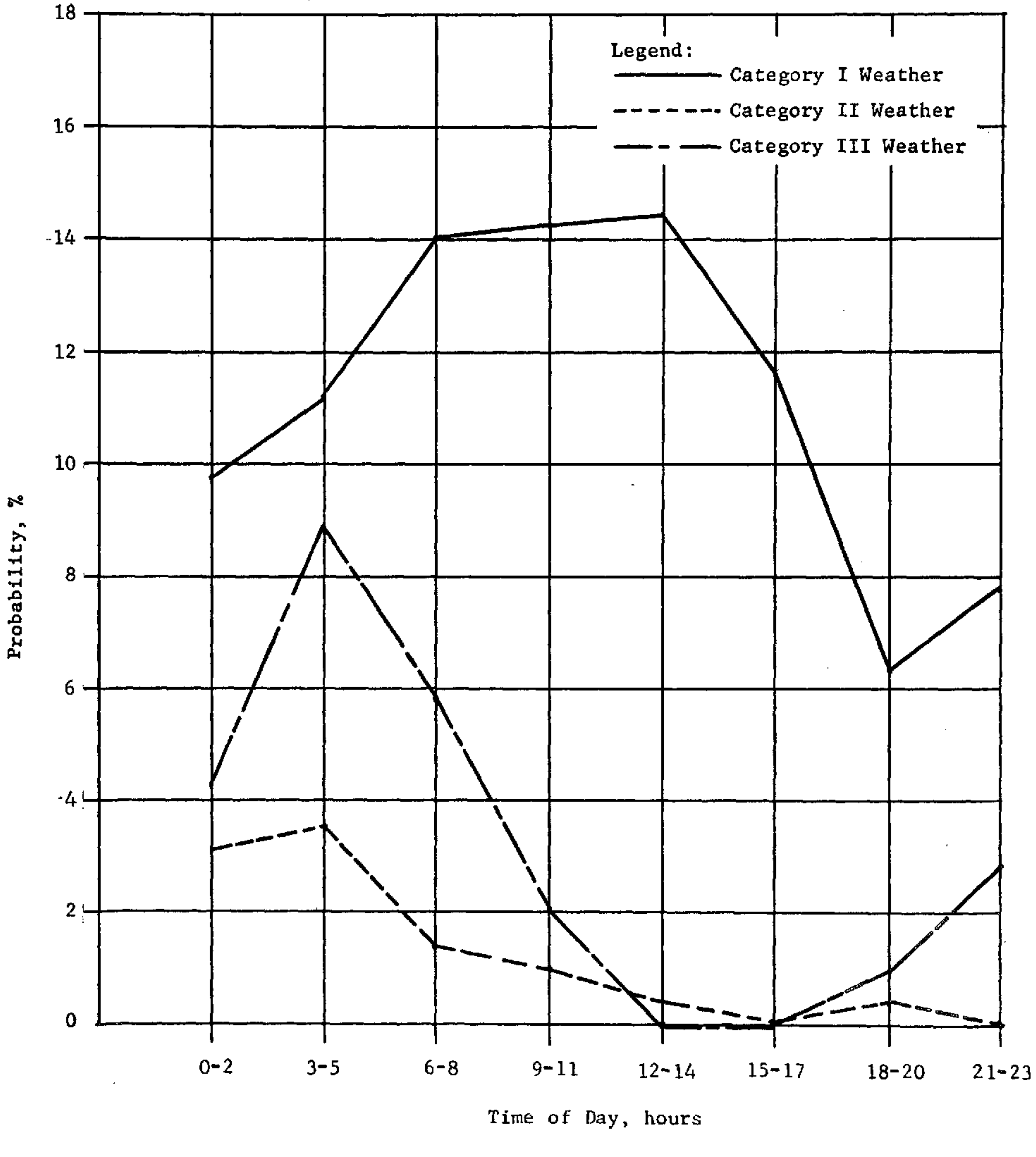


FIGURE A-14. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR FEBRUARY AT SANTA ANA, CALIFORNIA

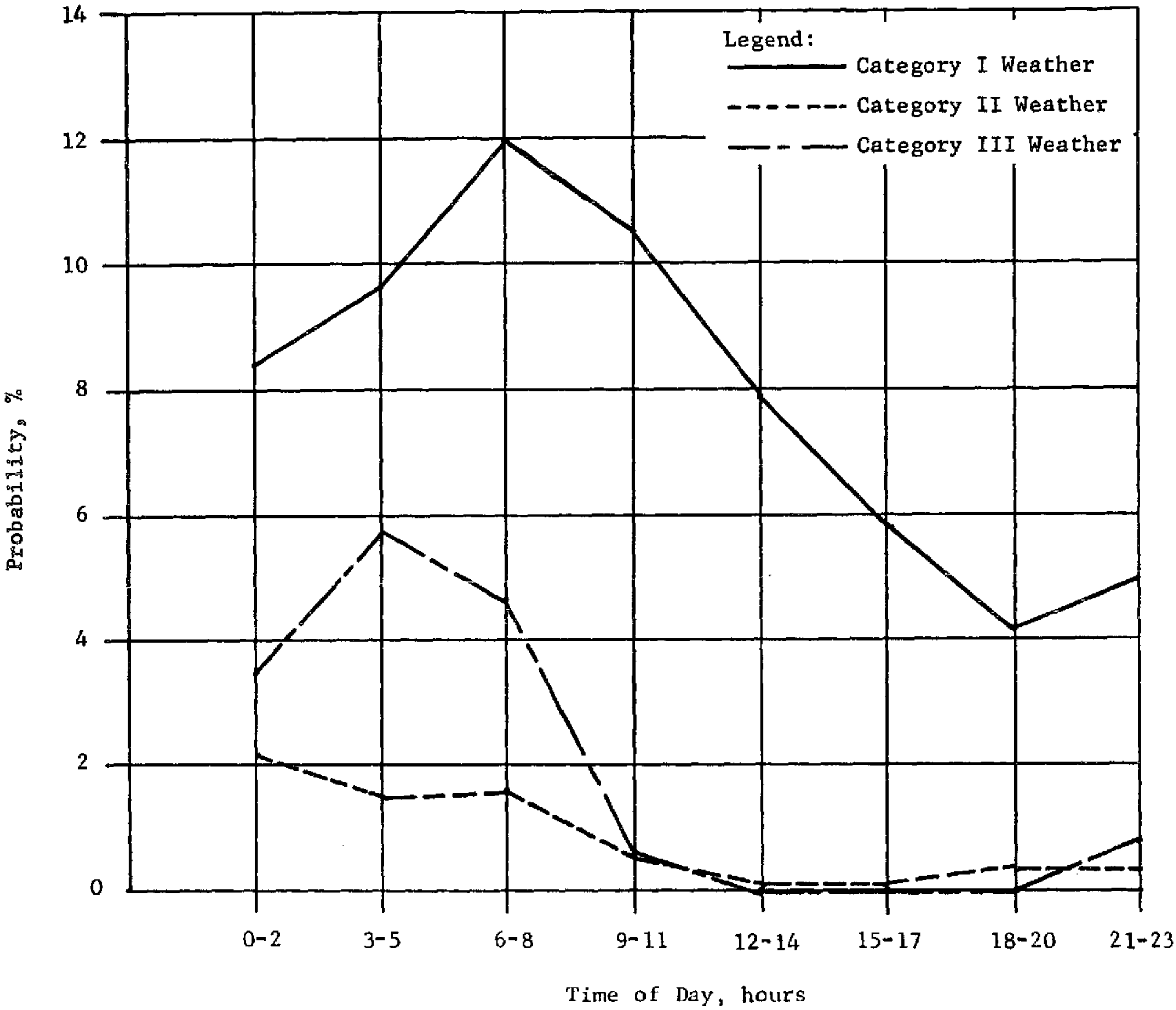


FIGURE A-15. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR MARCH AT SANTA ANA, CALIFORNIA

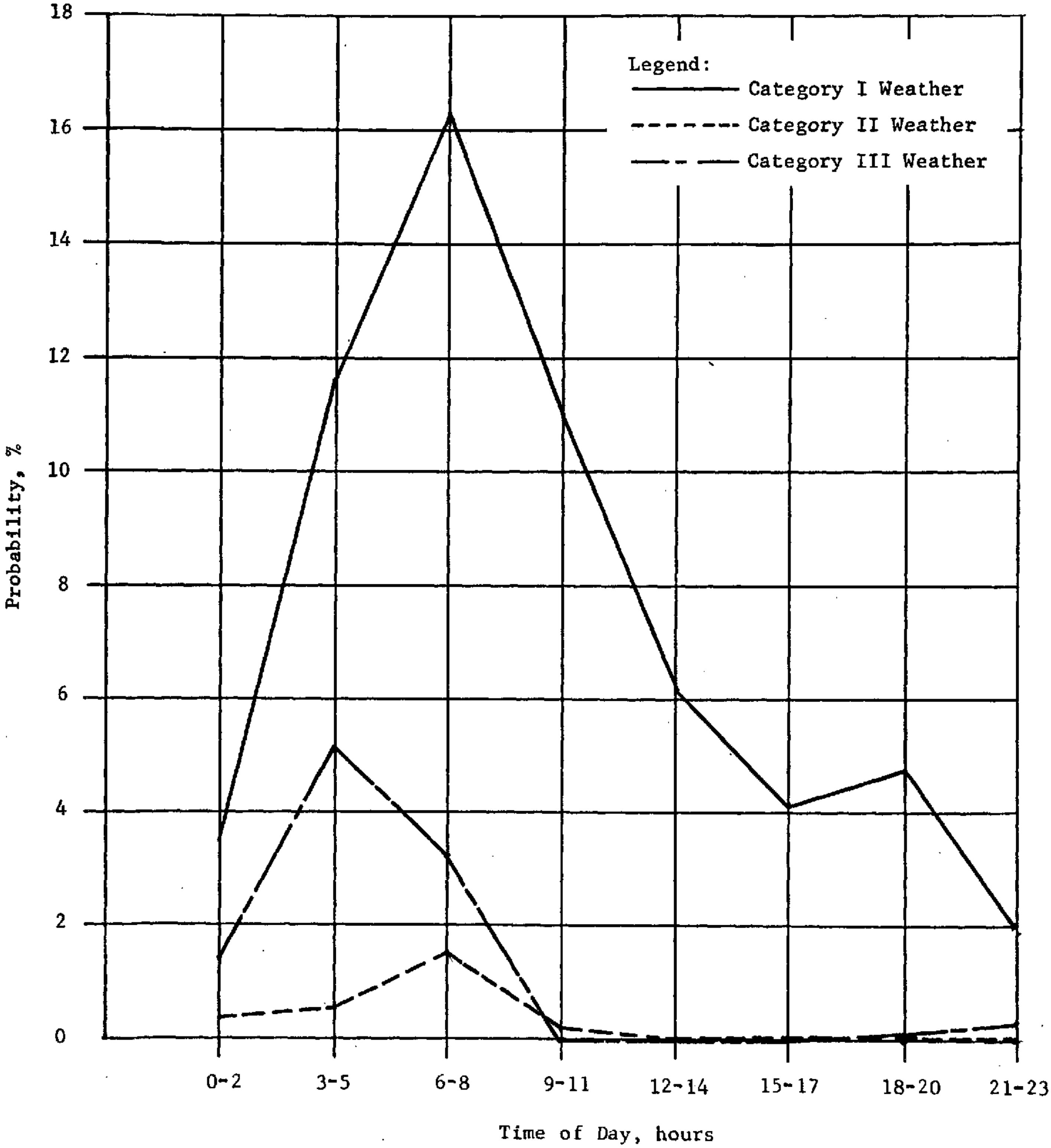


FIGURE A-16. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR APRIL AT SANTA ANA, CALIFORNIA

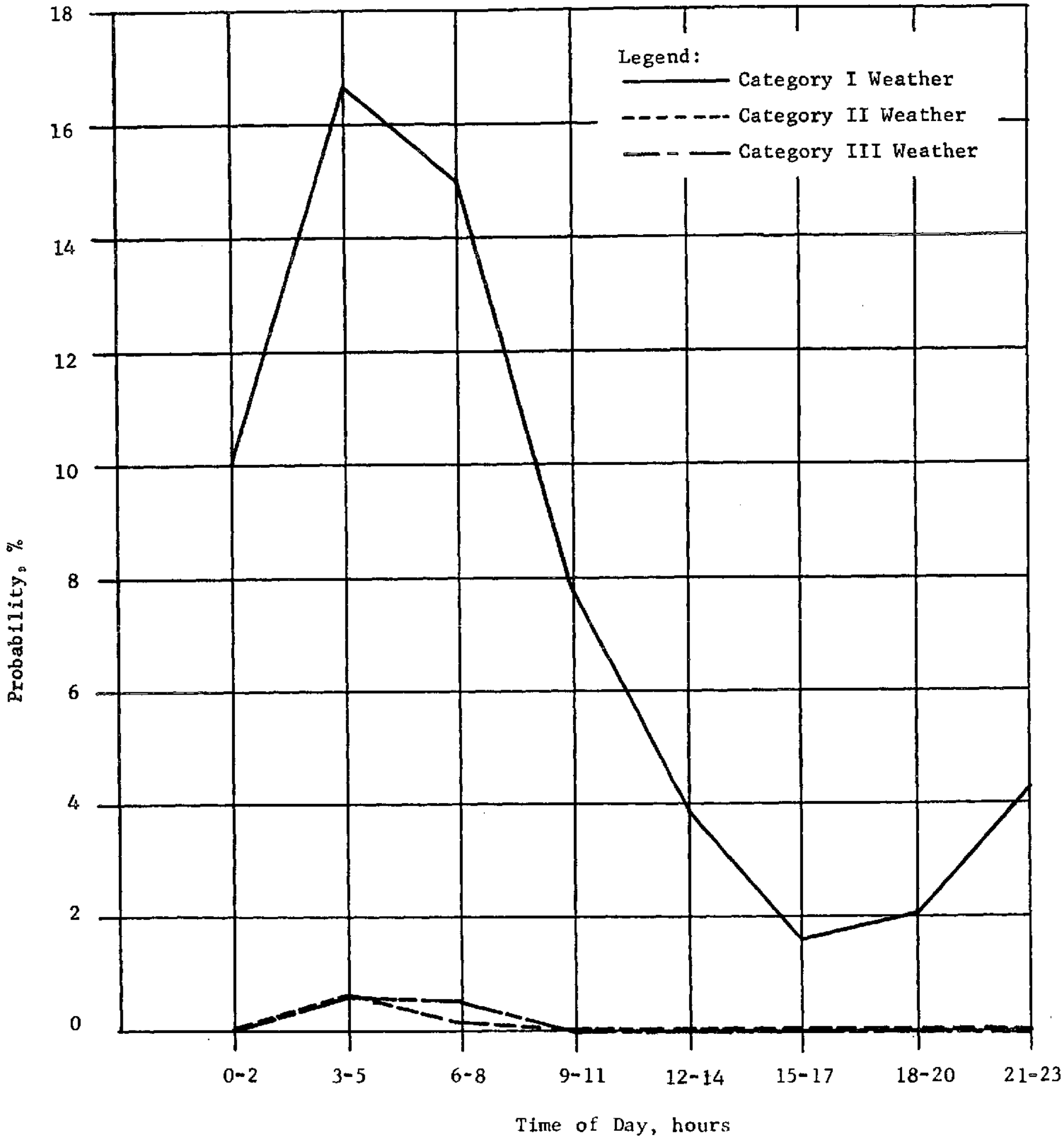


FIGURE A-17. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR MAY AT SANTA ANA, CALIFORNIA

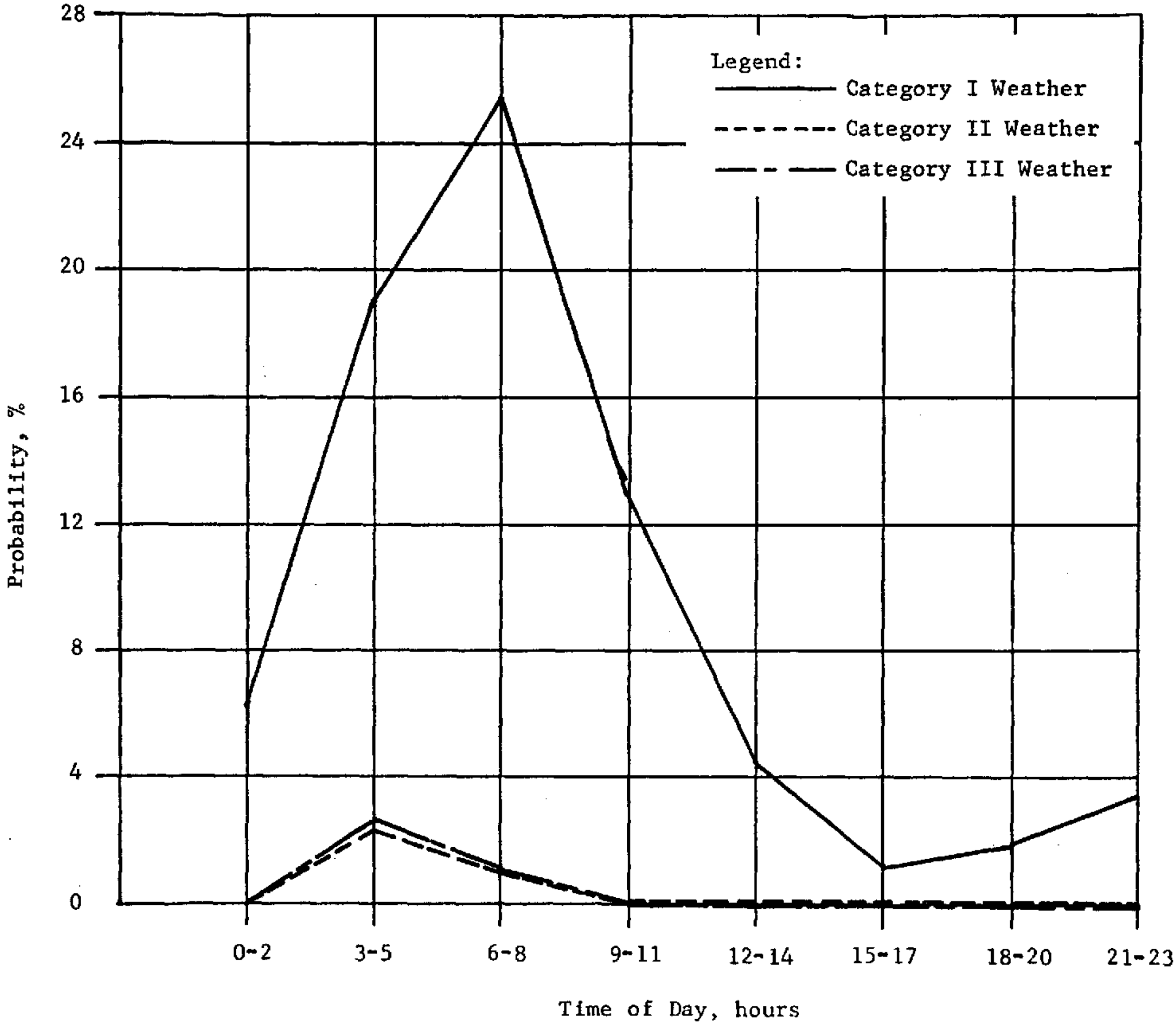


FIGURE A-18. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR JUNE AT SANTA ANA, CALIFORNIA

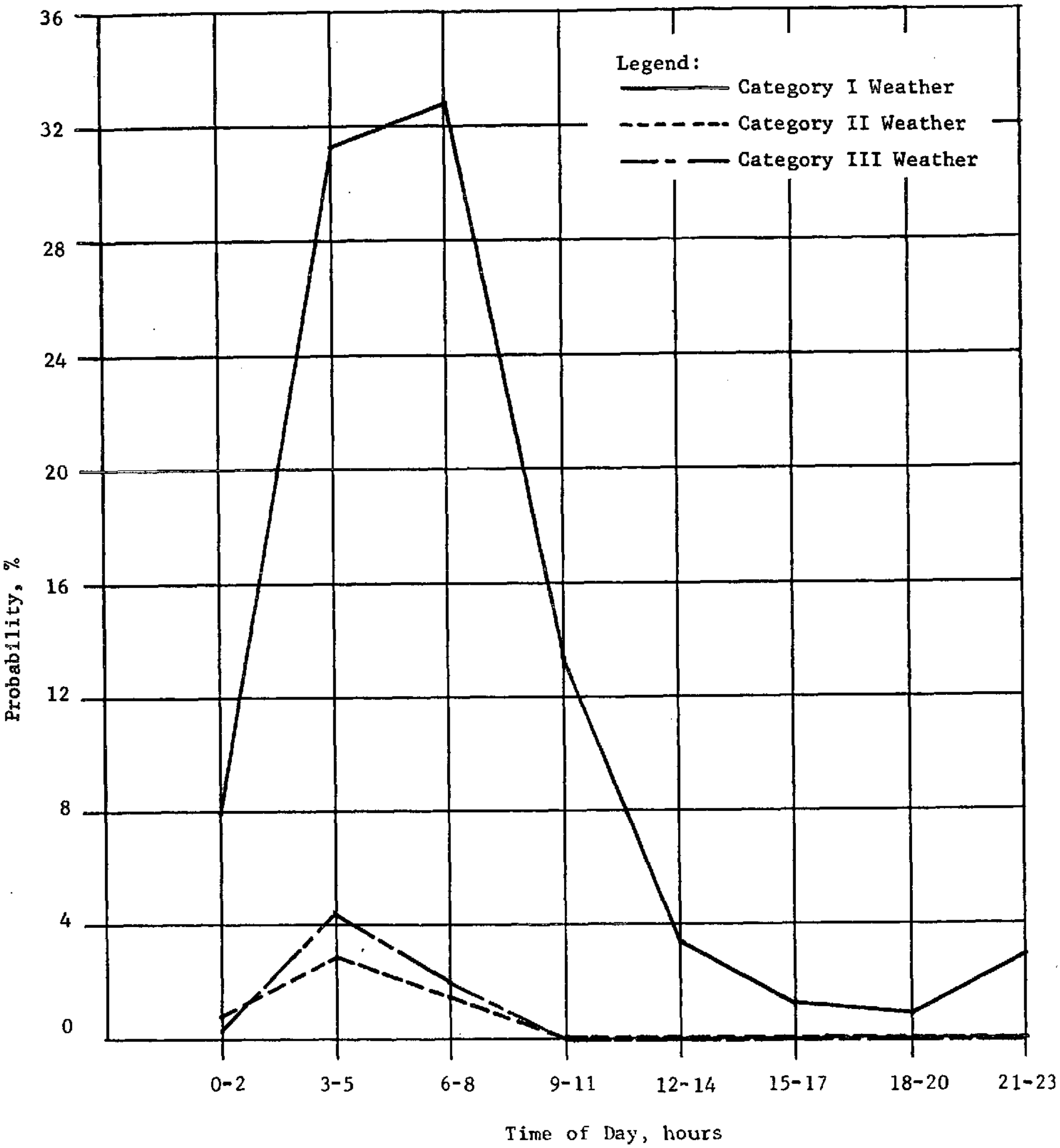


FIGURE A-19. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR JULY AT SANTA ANA, CALIFORNIA

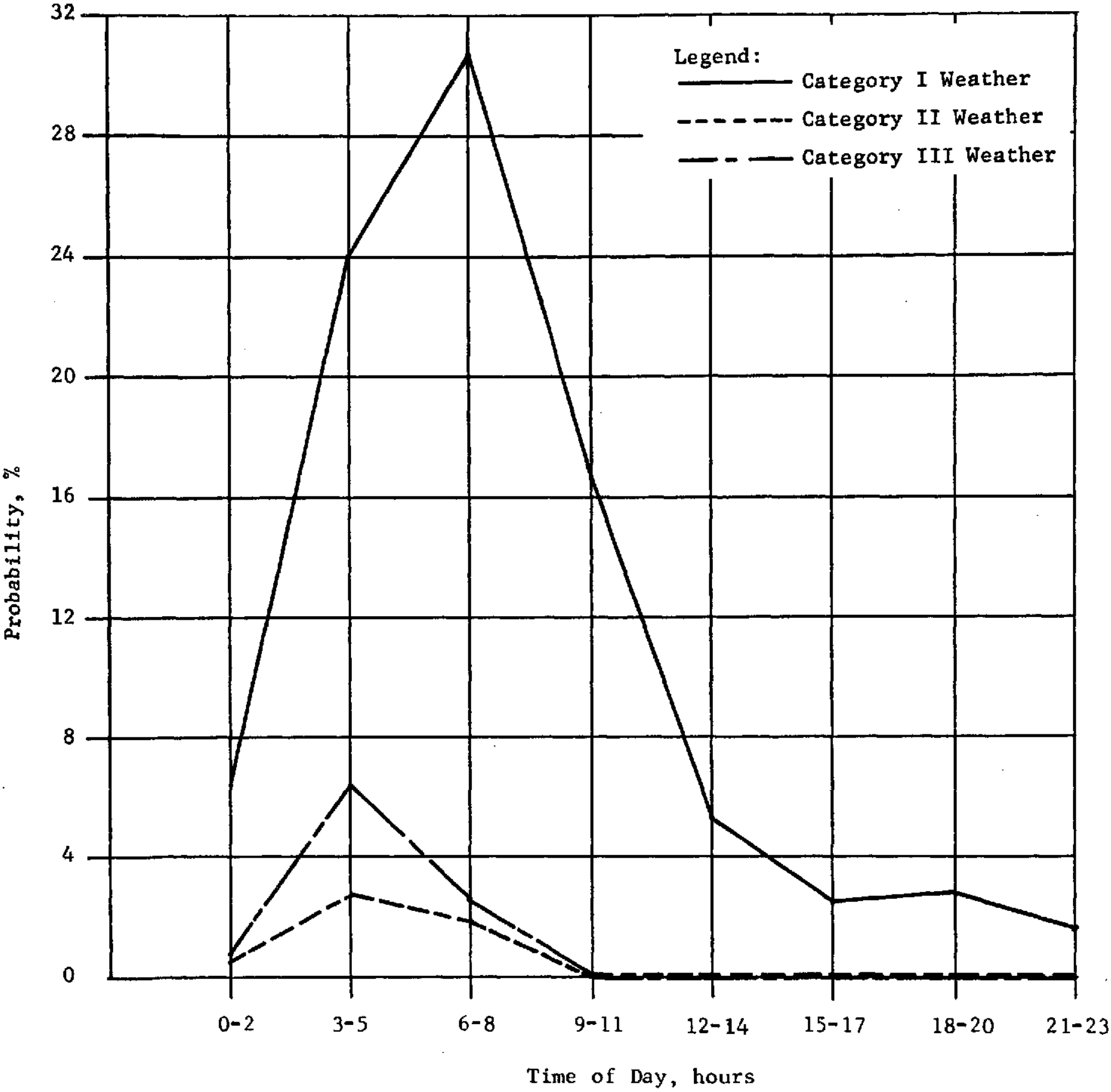


FIGURE A-20. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR AUGUST AT SANTA ANA, CALIFORNIA

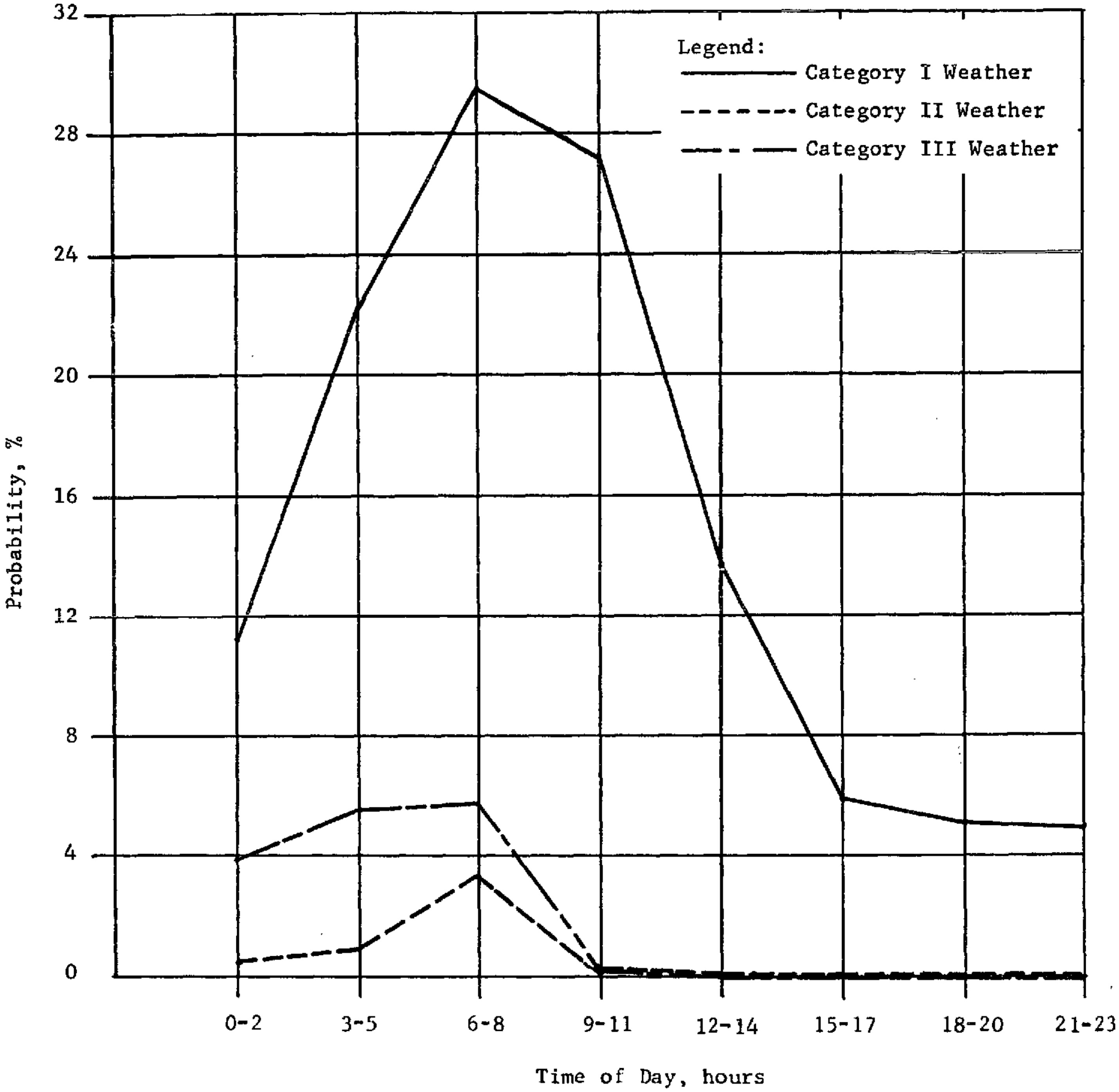


FIGURE A-21. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR SEPTEMBER AT SANTA ANA, CALIFORNIA

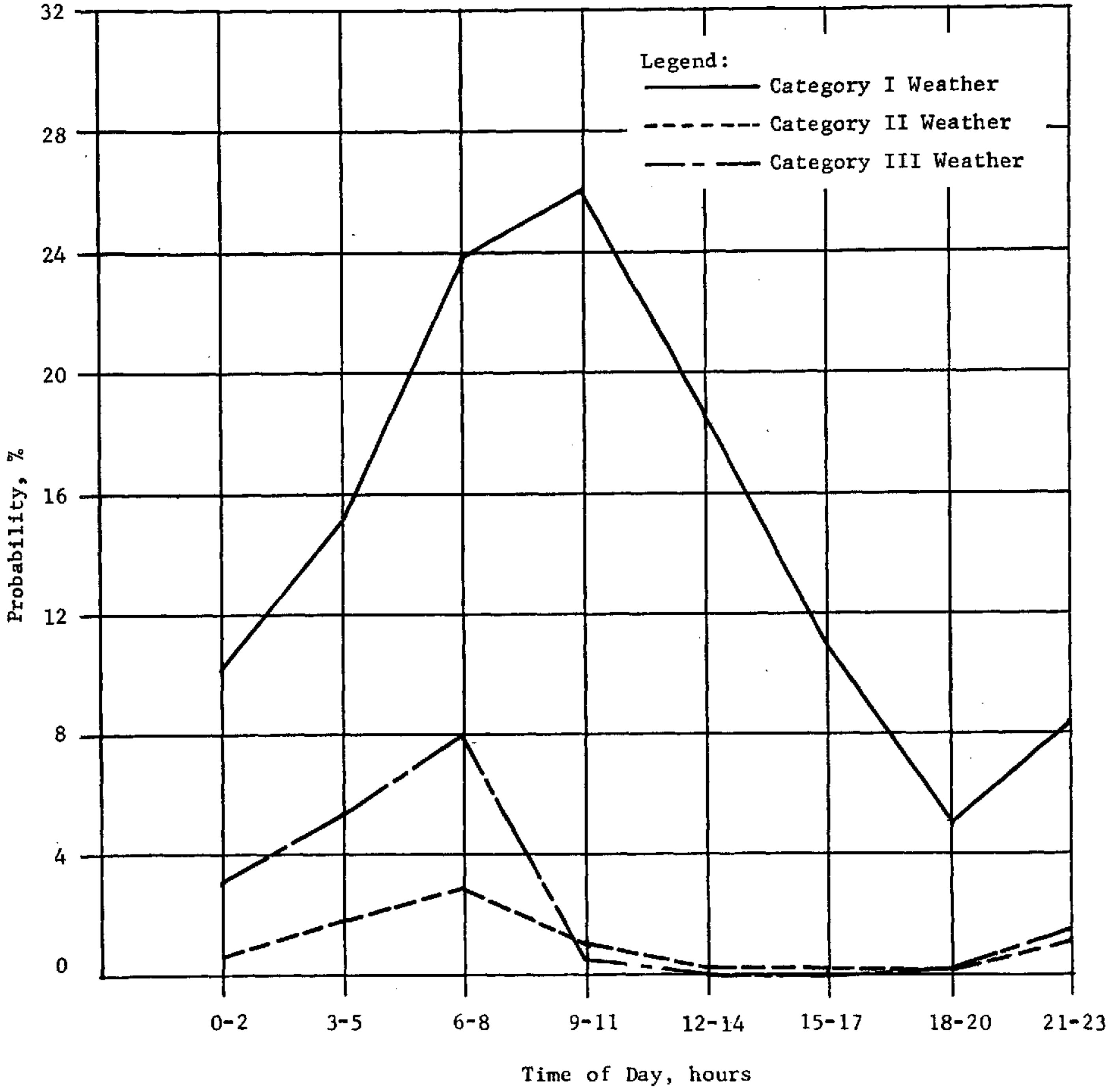


FIGURE A-22. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR OCTOBER AT SANTA ANA, CALIFORNIA

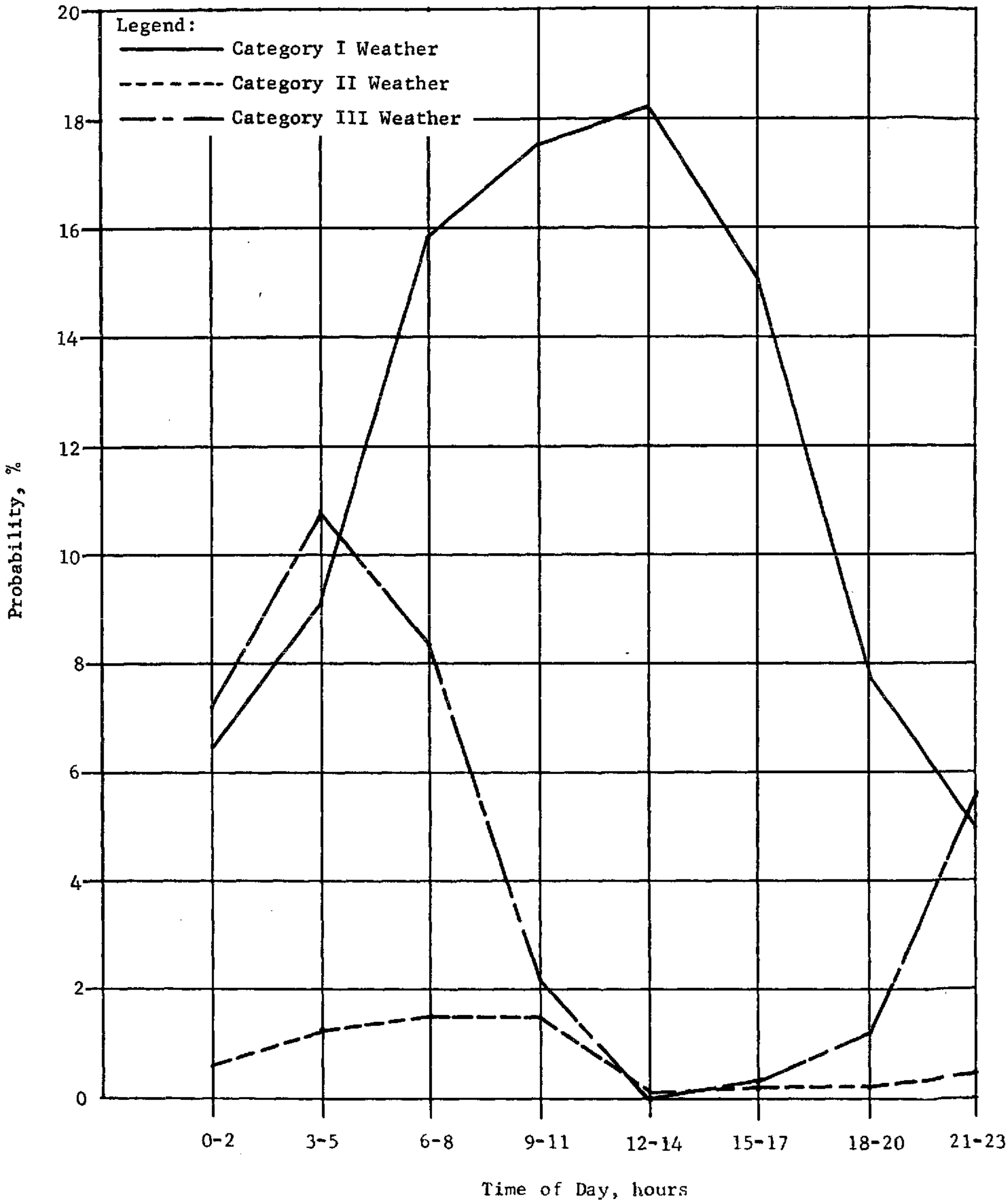


FIGURE A-23. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR NOVEMBER AT SANTA ANA, CALIFORNIA

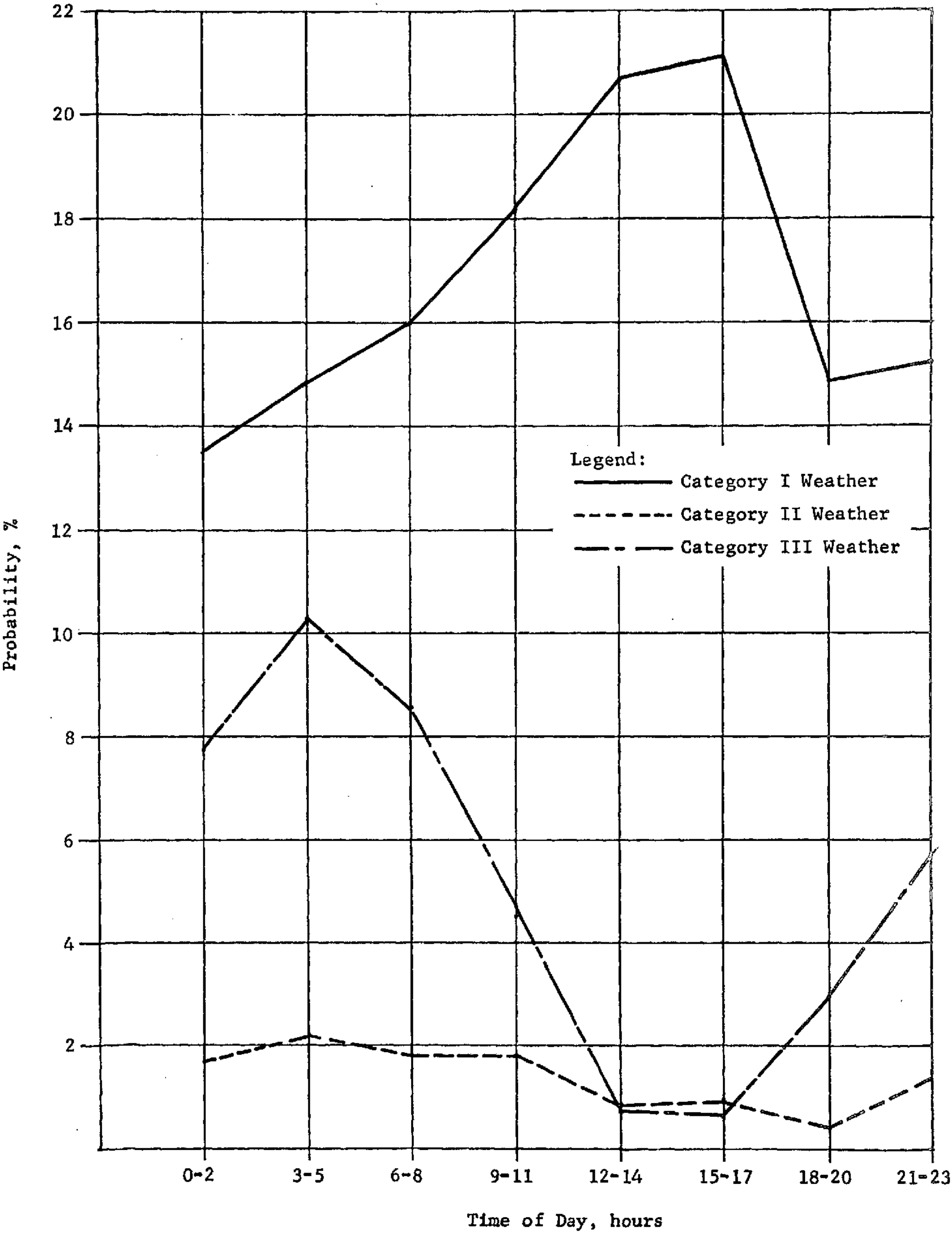


FIGURE A-24. PROBABILITY OF LOW VISIBILITY WEATHER CONDITIONS FOR DECEMBER AT SANTA ANA, CALIFORNIA

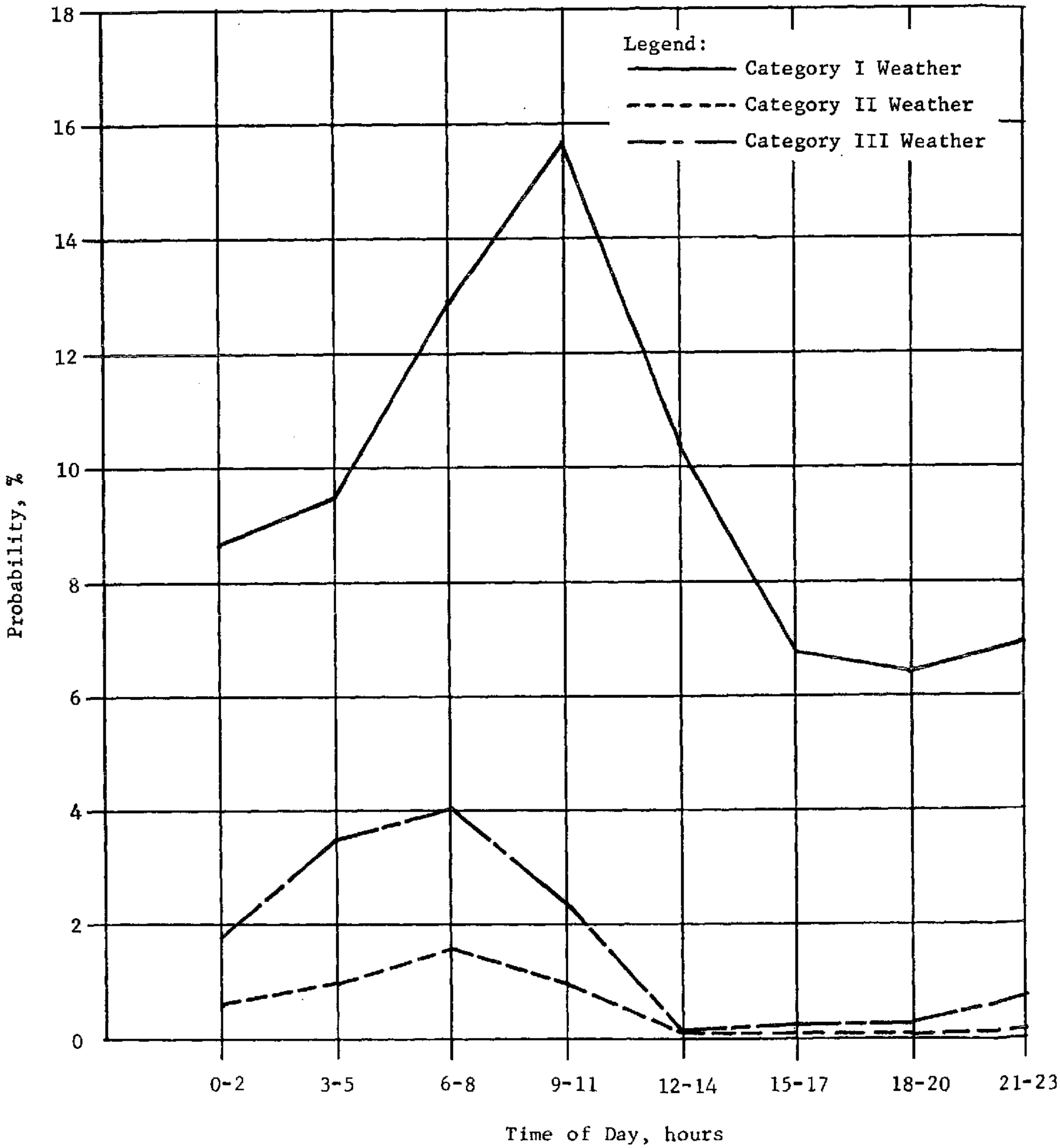


FIGURE A-25. AVERAGE PROBABILITY OF LOW VISIBILITY WEATHER AT MOFFETT FIELD, CALIFORNIA FOR THE WINTER MONTHS (NOVEMBER-MARCH)

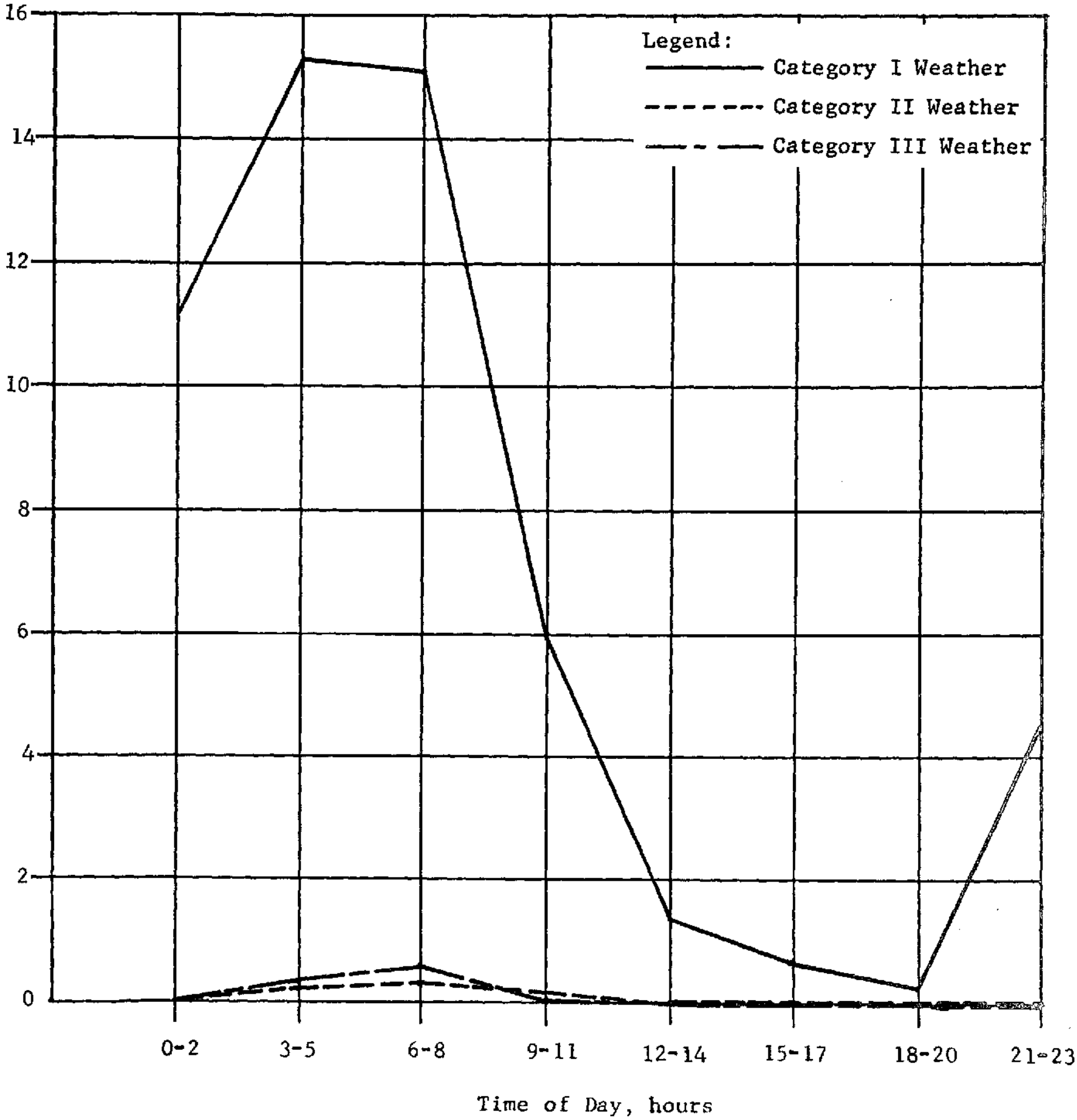


FIGURE A-26. AVERAGE PROBABILITY OF LOW VISIBILITY WEATHER AT MOFFETT FIELD, CALIFORNIA FOR THE SUMMER MONTHS (APRIL-OCTOBER)

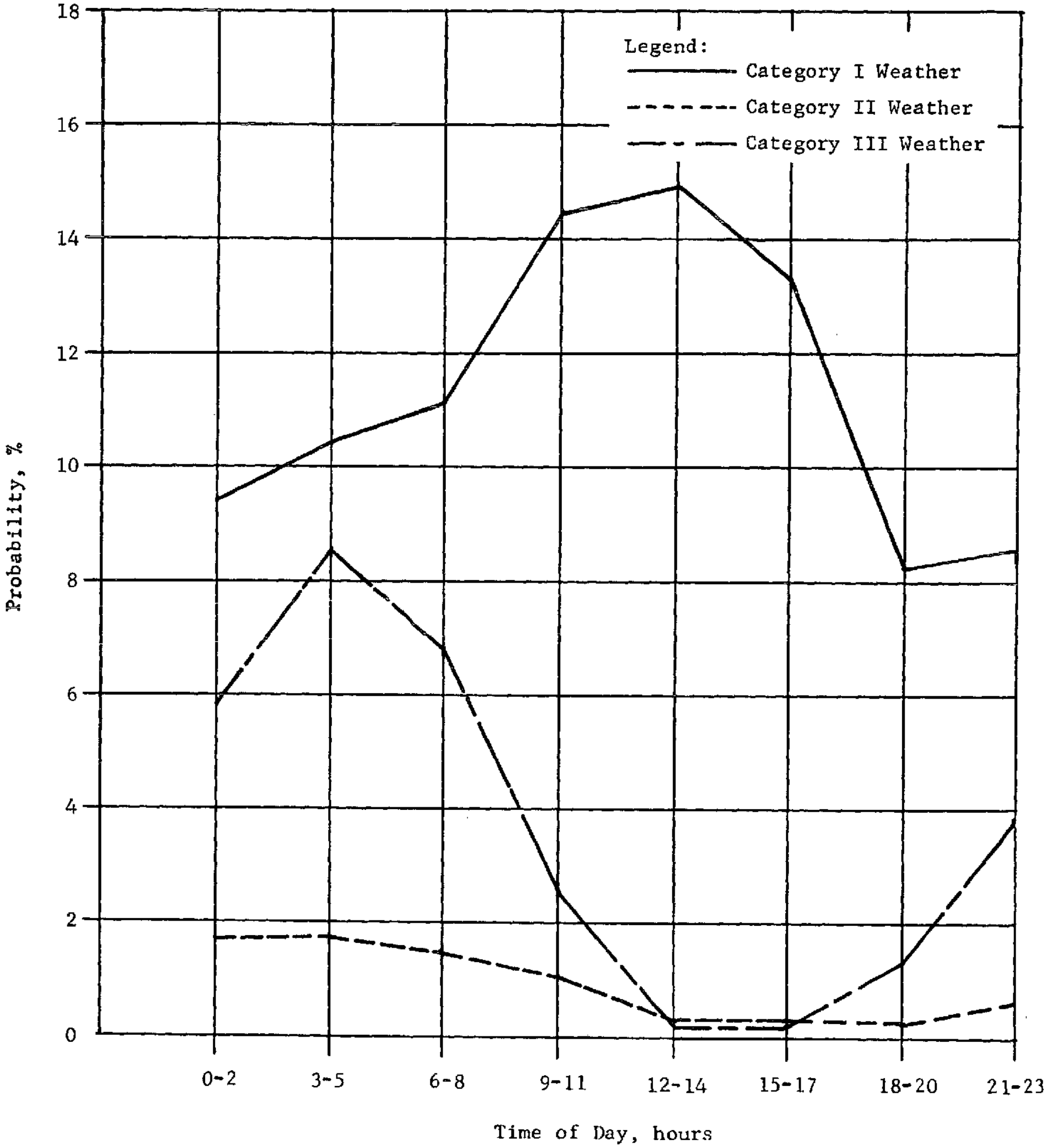


FIGURE A-27. AVERAGE PROBABILITY OF LOW VISIBILITY WEATHER AT SANTA ANA, CALIFORNIA FOR THE WINTER MONTHS (NOVEMBER-MARCH)

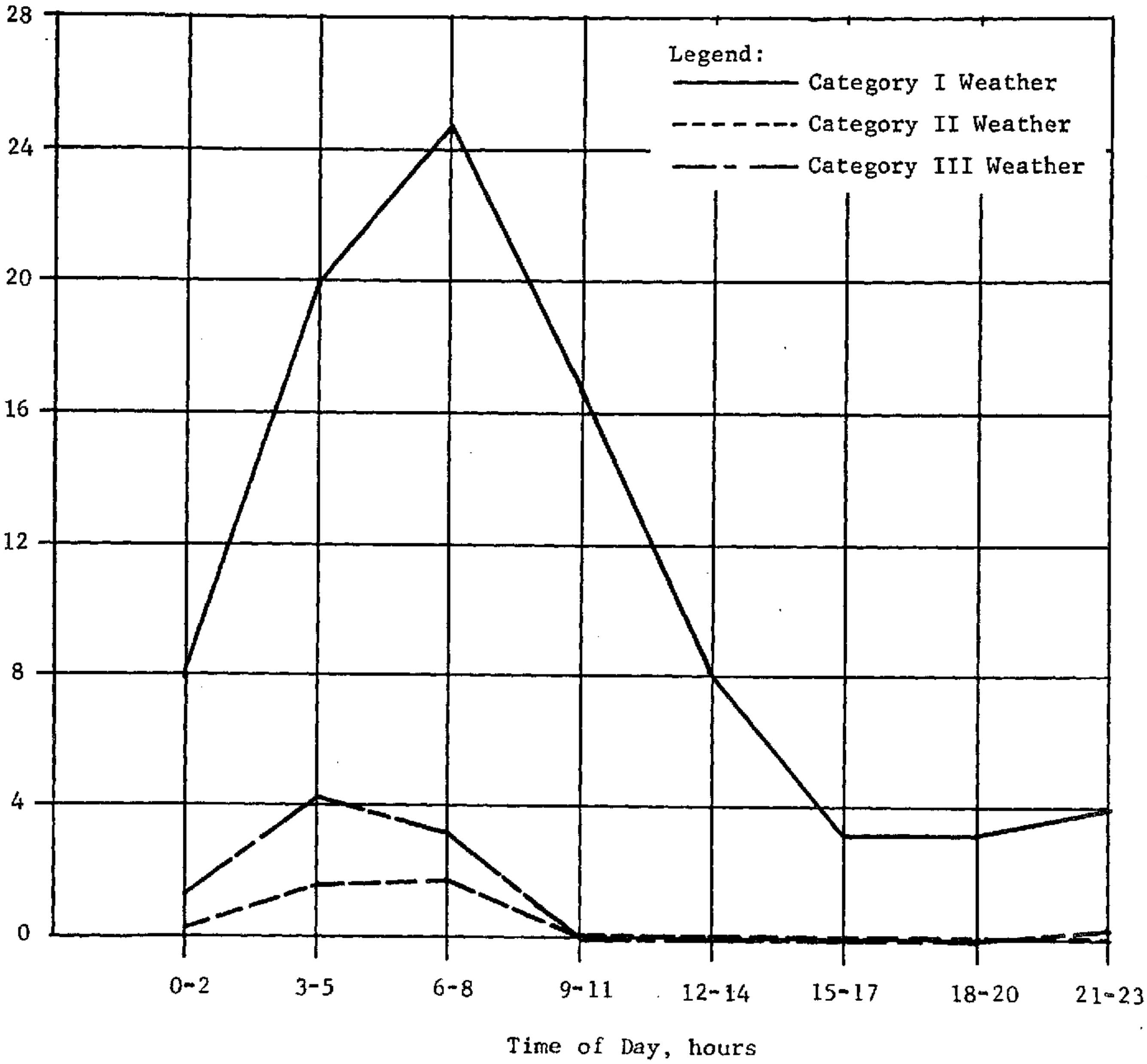


FIGURE A-28. AVERAGE PROBABILITY OF LOW VISIBILITY WEATHER AT SANTA ANA, CALIFORNIA FOR THE SUMMER MONTHS (APRIL-OCTOBER)

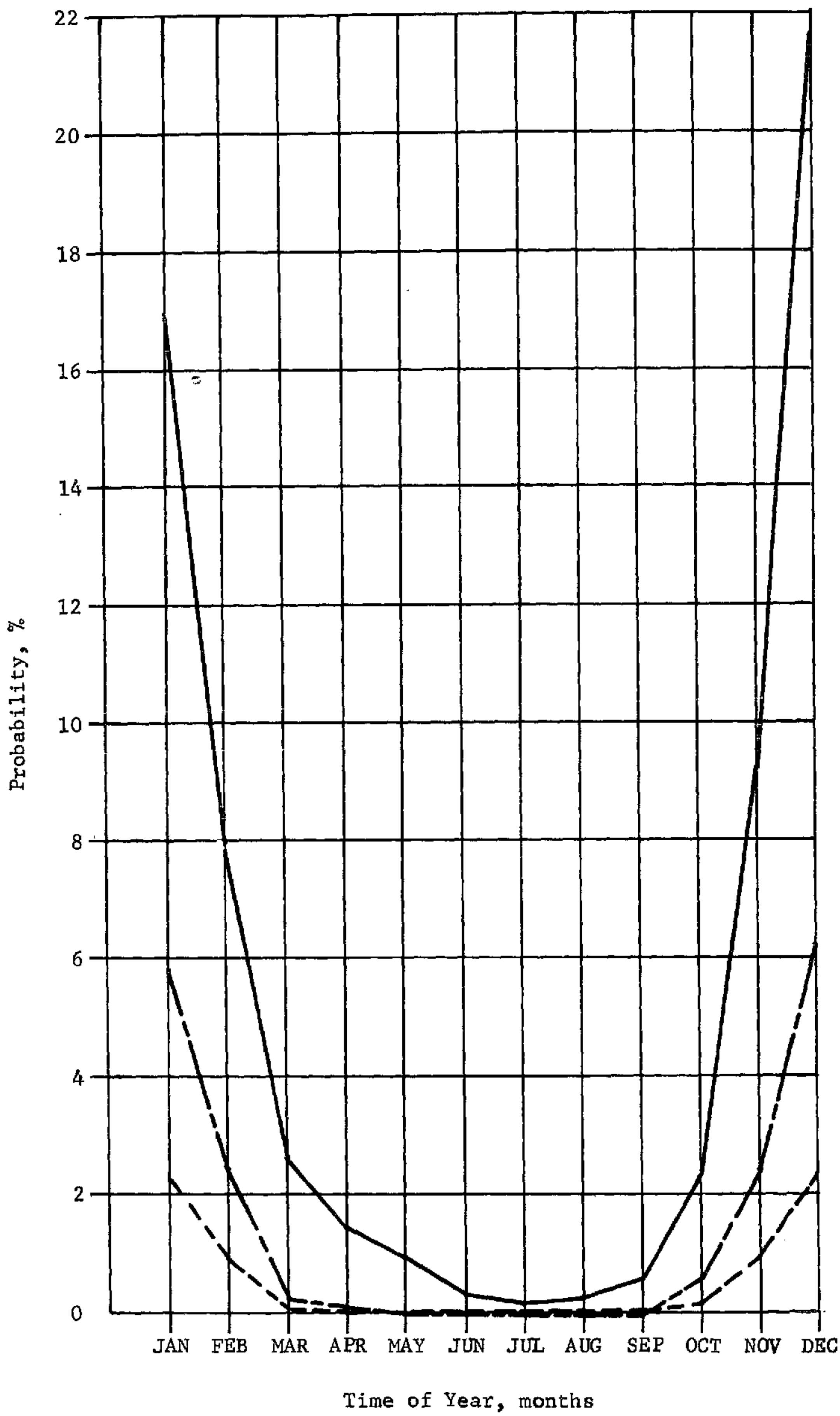


FIGURE A-29. AVERAGE PROBABILITY OF LOW VISIBILITY WEATHER AT McCLELLAN AFB, CALIFORNIA FOR A YEARLY CYCLE

TABLE A-3. NUMBER OF OCCURRENCES OF GIVEN DURATION DURING A TEN-YEAR PERIOD

Duration (min)	Oakland Category II	Oakland Category III	Los Angeles Category II	Los Angeles Category III
1-15	116	22	445	78
16-30	72	28	161	74
31-45	45	30	89	50
46-60	33	21	42	31
61-90	15	27	37	63
91-120	9	17	17	36
121-180	4	22	15	46
181-240	3	19	5	34
241-360	1	14	0	45
361-480	0	10	0	25
480+	0	20	0	17
Total	298	230	811	499

Note: Data are for all seasons and all hours for January 1956 January, 1956 to December, 1965.

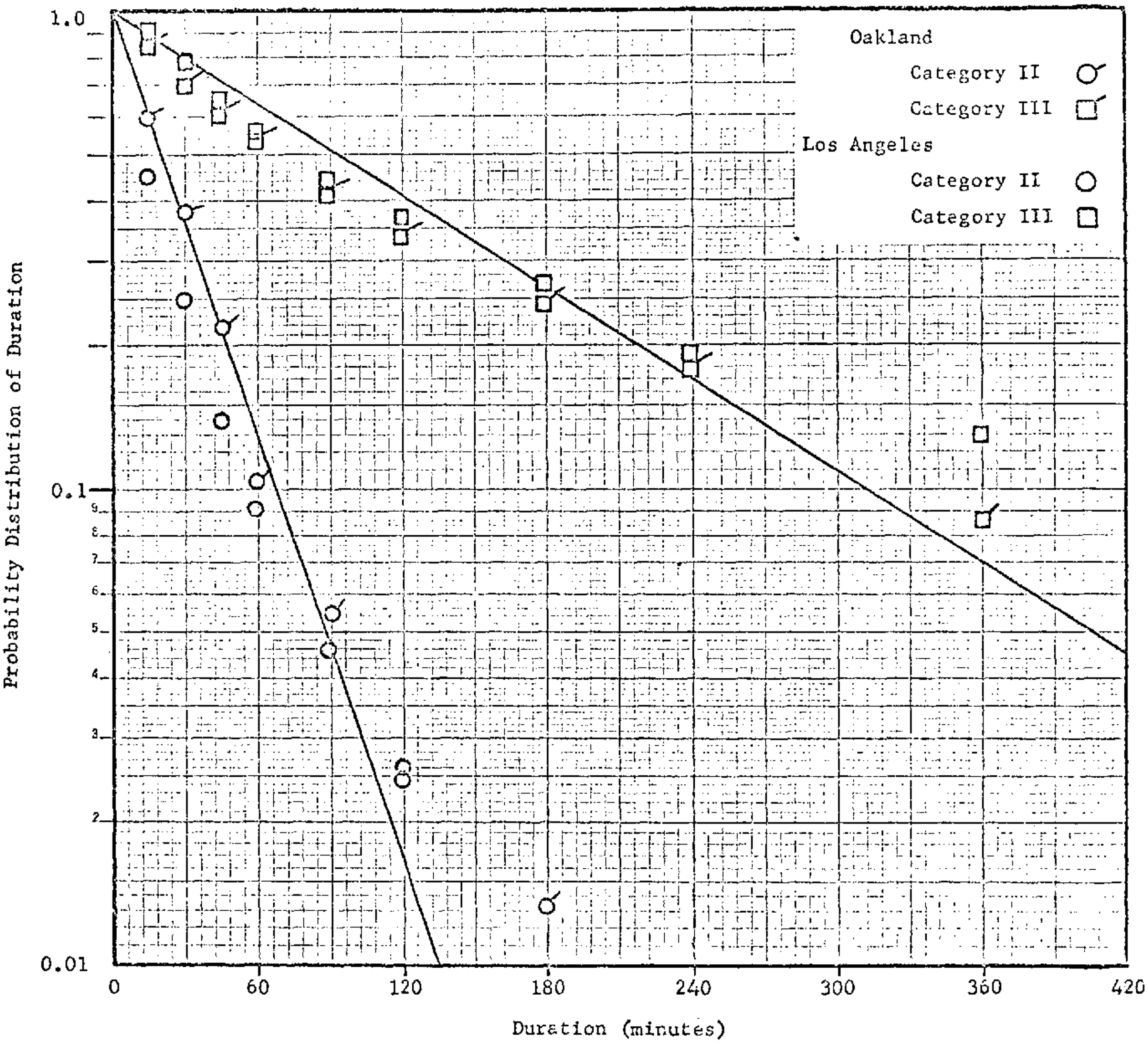


FIGURE A-30. PROBABILITY DISTRIBUTION OF DURATION

APPENDIX A

1. The duration times for each category will be the same for all three airports. This assumption is made to accommodate the lack of data for Sacramento and because of the good correlation of data for Oakland and Los Angeles.

2. The probability of remaining in a category is exponentially dependent on duration (straight line fit on a semi-logarithmic graph). This fit gives the following expenential probability distribution functions:

   Probability of the duration of Category II for

   $$t \text{ minutes} = e^{-.0341t} ,$$

   Probability of the duration of Category III for

   $$t \text{ minutes} = e^{-.0071t} .$$

   The expected value (mean) of the exponential probability distribution is the inverse of the exponential coefficient or:

   $$\text{Mean duration of Category II conditions} = \frac{1}{.0341} = 29.32 \text{ minutes.}$$

   $$\text{Mean duration of Category III conditions} = \frac{1}{.0071} = 140.0 \text{ minutes.}$$

No data were found on the correlation time of Category I weather. However, a Congressional airport congestion study(2) contains two weeks (September 16-29, 1970) of IFR histories at Los Angeles and San Francisco. The histories are in the form of hours of IFR weather during that period. The data are scant with 11 occurrences at Los Angeles and only five at San Francisco as shown below:

Duration of occurrences of IFR Conditions (hr):

Los Angeles	1, 2, 3, 3, 3, 5, 5, 7, 9, 12, 13
San Francisco	1, 1, 2, 5, 5

The average duration for both airports taken together is 4.8 hr. For the model described below, a mean duration of 200 min for Category I yields a mean duration of 4.5 hr for IFR weather.

In summary, the following probability density functions were chosen based on the available data.

Category I : $e^{-.005t}$, 200 min

Category II : $e^{-.034t}$, 29 min

Category III: $e^{-.0071t}$, 140 min

Weather Category Transition Logic

Figure A-31 shows a model for weather category transition. The q_{ij} represent the intensity of transition from state i to state j. For example, if the weather at time t is Category I, the probability that Category II occurs a small time later is

$$\Pr\{\text{Cat. II at } t + \Delta t\} \approx q_{12}\Delta t \quad .$$

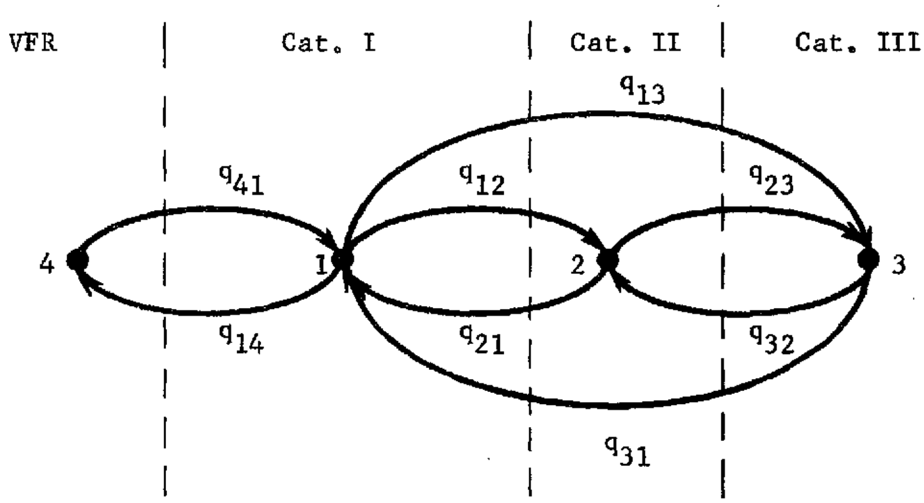


FIGURE A-31. CATEGORY TRANSITION MODEL

APPENDIX A

The probabilities of weather categories satisfy the following matrix differential equation(3):

$$\dot{P} = Q\,P$$

where

$$P = \begin{bmatrix} P_1 \triangleq \text{prob. of Cat. I} \\ P_2 \triangleq \text{prob. of Cat. II} \\ P_3 \triangleq \text{prob. of Cat. III} \\ P_4 \triangleq \text{prob. of VFR} \end{bmatrix}$$

$$Q = \begin{bmatrix} -(q_{12} + q_{13} + q_{14}) & q_{21} & q_{31} & q_{41} \\ q_{12} & -(q_{21} + q_{23}) & q_{32} & 0 \\ q_{13} & q_{23} & -(q_{31} + q_{32}) & 0 \\ q_{14} & 0 & 0 & -q_{41} \end{bmatrix} .$$

The probability function defining the duration of a given state is:

$$P_{ii}(t) = P_r\{\text{Leave state } i \text{ at } t/\text{in state } i \text{ at } t = 0\} .$$

For the above model

$$P_{ii}(t) = e^{q_{ii}t} .$$

As an example, the probability function for Category II is:

$$P_{22}(t) = e^{-(q_{21} + q_{23})t} .$$

For the model to be compatible with observed data for Categories II and III, the following equations must hold:

$$q_{21} + q_{23} = 0.034$$

$$q_{31} + q_{32} = 0.0071 .$$

APPENDIX A

Since data describing the occurrence of weather categories are available for 3 hr periods, the remaining q_{ij} are chosen for each 3-hr period so that the resultant probabilities will closely match the given data. It was found that a mean duration of 200 min for Category I would yield a close match to the mean duration of IFR weather shown in the previous section. Thus, the following additional constraint was imposed on the q_{ij}'s:

$$q_{12} + q_{13} + q_{14} = 0.005 \quad .$$

Figures A-32, A-33, and A-34 show a comparison of the model results and the available data for Categories I, II, and III at San Jose.

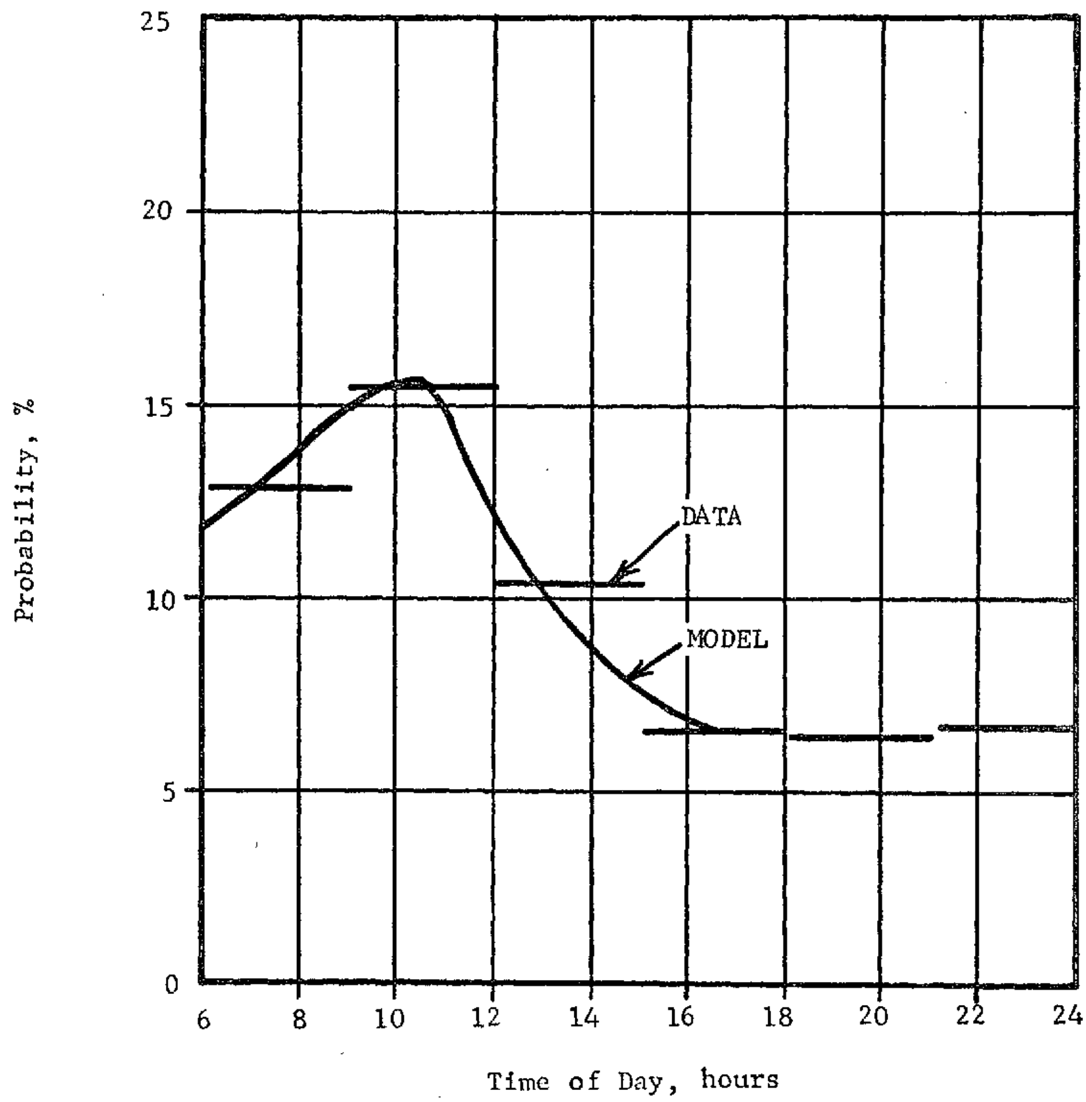


FIGURE A-32. COMPARISON OF MODEL RESULTS AND DATA FOR CATEGORY I WEATHER

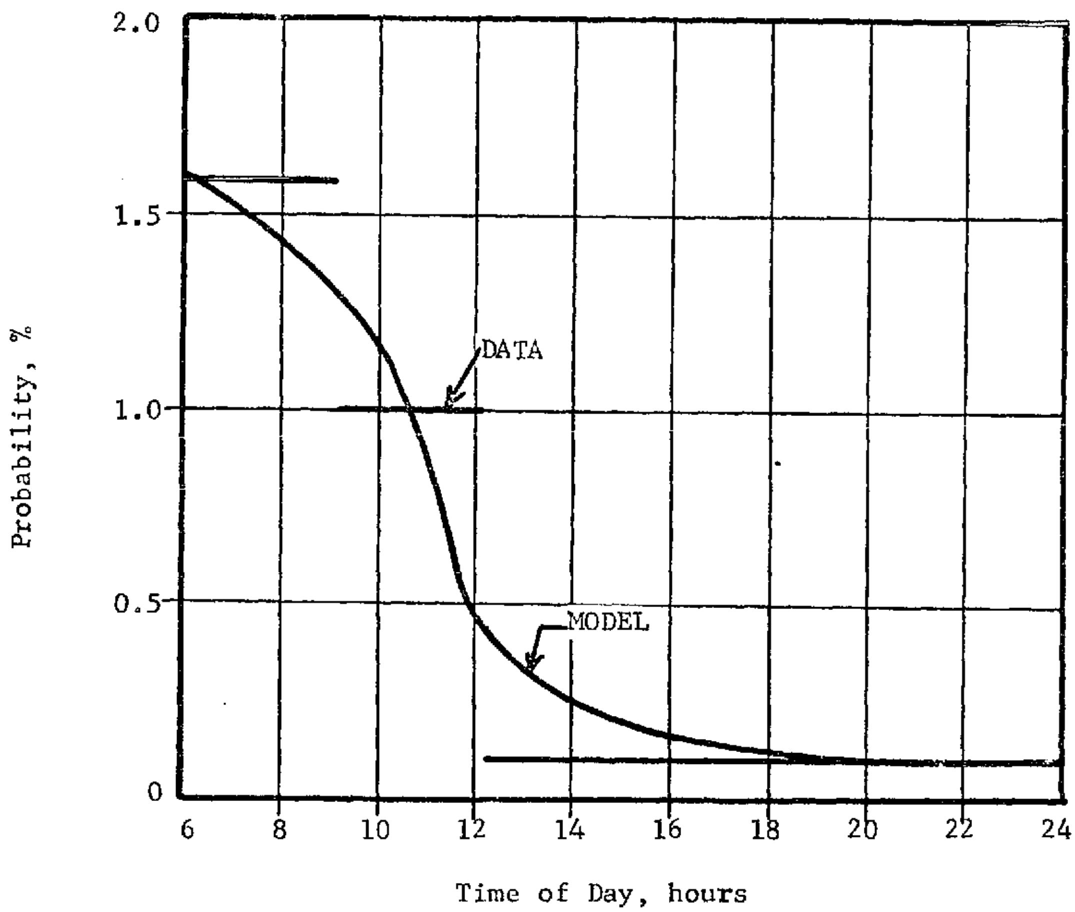


FIGURE A-33. COMPARISON OF MODEL RESULTS AND DATA FOR CATEGORY II WEATHER

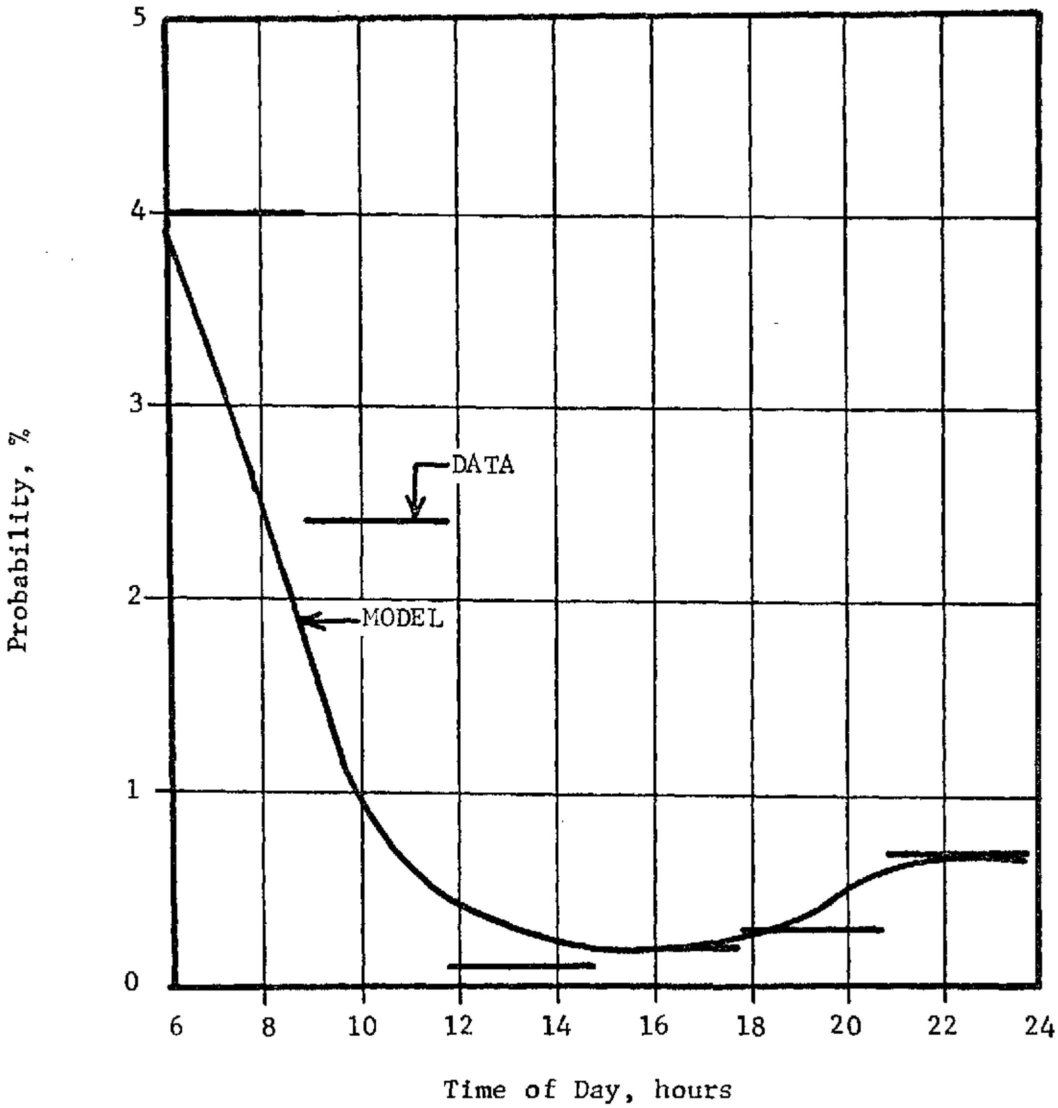


FIGURE A-34. COMPARISON OF MODEL RESULTS AND DATA FOR CATEGORY III WEATHER

APPENDIX A

REFERENCES

(1) Climatological Summaries, SRDS Report No. RD-69-22, Vol. 30, Oakland, California; Vol. 20, Los Angeles, California, 1969.

(2) Constanz, J. C., "Congressional Airport Congestion Study", Part 2 (1970).

(3) Parzen, E., "Stochastic Processes", Holden-Day, Inc. (1962).

APPENDIX B

MANEUVERING LIMITATIONS WITHIN MLS COVERAGE

APPENDIX B

MANEUVERING LIMITATIONS WITHIN MLS COVERAGE

This appendix contains a set of plots showing maneuvering limitations within MLS coverage. The purpose of these plots is to obtain some graphical insight into the relationship between MLS angular coverage and aircraft turning maneuvers. Each plot shows a maneuver which starts outside the MLS coverage. The plots depict the minimum distance which is required to complete the indicated maneuver referenced to the MLS azimuth antenna. The number to the right of the start of each trace is the inbound heading, where zero degrees is the final approach direction. These paths were calculated assuming the the first turn begins one second after entering the MLS coverage and that maximum bank angles and bank angle rates are used throughout the maneuver. It is also assumed that the aircraft can instantaneously achieve the desired bank angle rates. These maneuvers are clearly not practical. However, they do show the airspace limitations imposed by a given set of aircraft, MLS, and wind conditions.

Table B-1 is an index of the plots. A dot near a Figure number indicates that the MLS coverage does not constrain maneuvers for that condition. That is, there is room for almost any maneuver before reaching the common path.

To find a plot for a specified set of parameters, Table B-1 is used as follows. The varied parameters are:

V = aircraft true air speed in knots,
φ_m = aircraft bank angle limit in degrees,
ψ_{az} = MLS azimuth angle in degrees,
x_{cp} = common path length in nautical miles,
W = wind velocity in knots.

As an example, for $W = 40$, $\psi_{az} = 40$, $x_{cp} = 1$, $\varphi_m = 25$ and $V = 110$, enter row five, column four. The specified plot is on Figure B-25.

TABLE B-1. FIGURE REFERENCE FOR THE PLOTS OF MANEUVER LIMITATIONS

φ_m/V Ψ_{az}/X_{cp}	W = 40			W = 0		
	25/110	25/95	25/80	15/110	15/95	15/80
20/1	B-1	B-2	B-3	B-4	B-5	B-6
20/2	B-7	B-8	B-9	B-10	B-11	B-12
20/3	B-13	B-14	B-15	B-16	B-17	B-18
20/4	B-19	B-20	B-21 ●	B-22	B-23	B-24 ●
40/1	B-25	B-26	B-27	B-28	B-29	B-30
40/2	B-31	B-32 ●	B-33 ●	B-34	B-35 ●	B-36 ●
40/3	B-37 ●	B-38 ●	B-39 ●	B-40 ●	●	●
40/4	B-41 ●	B-42 ●	B-43 ●	B-44 ●	●	●
60/1	B-45	B-46 ●	B-47 ●	B-48 ●	●	●
60/2	B-49 ●	B-50 ●	B-51 ●	●	●	●
60/3	●	●	●	●	●	●

● Indicates conditions under which two 180 degree turns can be made within the MLS coverage,

Ψ_{az} = maximum azimuth MLS angle in degrees

x_{cp} = common path length in miles

ϕ_m = aircraft bank angle limit in degrees

V = aircraft velocity in knots.

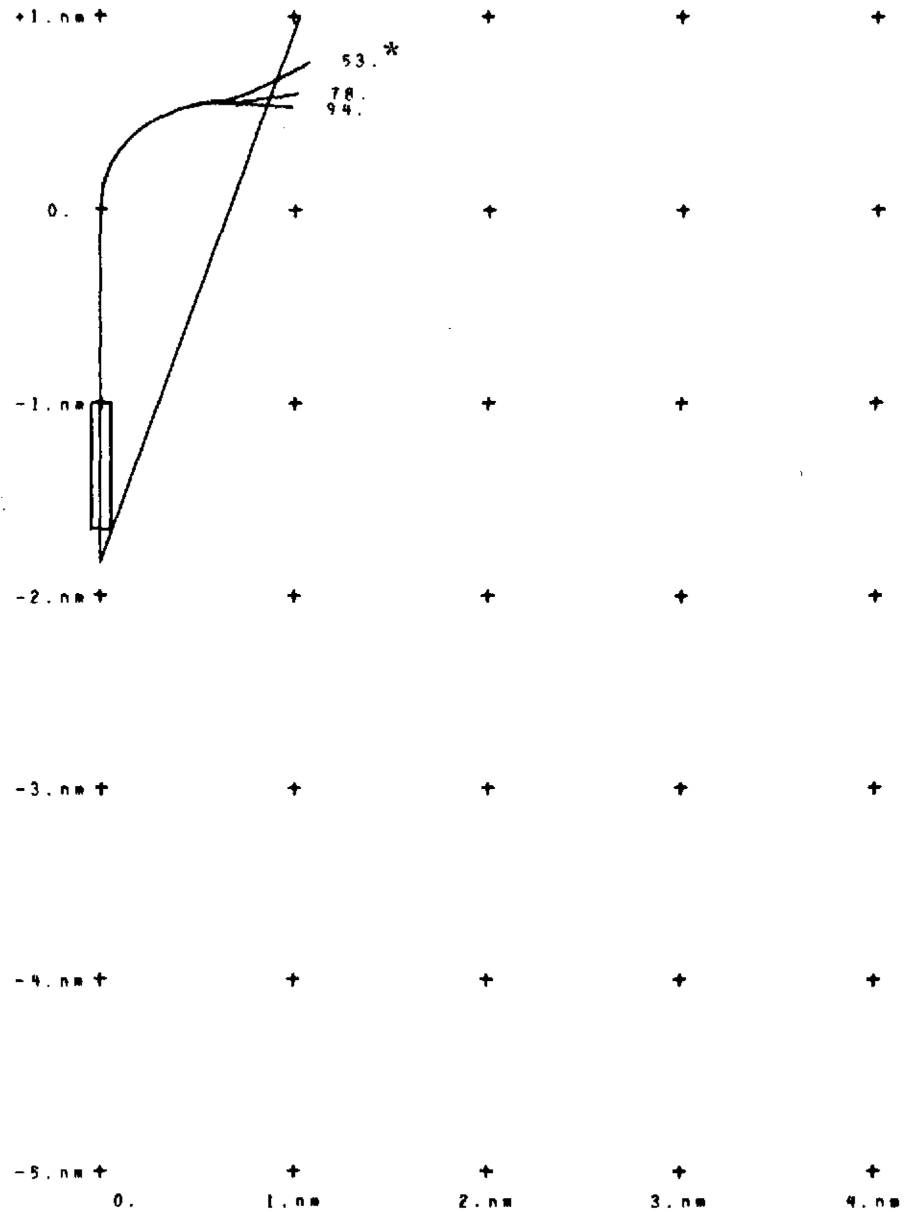
Two bank angles were selected for these plots; 15° and 25°. A 15° bank angle is a likely maximum nominal turn under no wind conditions. That is, it is unlikely that nominal paths would be established requiring turns at greater than 15° bank under no wind conditions. The 25° bank angle represents a reasonable autopilot bank angle limit (although this limit might well be as high as 30° or 35°). Thus, the conditions of interest for maneuvering limitations are plots at 15° bank angle with no wind and plots at 25° bank angle with worst case winds. These are the cases shown in Table B-1. A worst case wind at terminal area maneuvering altitudes is approximately 40 knots. The worst case direction is a tailwind when approaching perpendicular to the final path. All of the plots with wind reflect this case.

Referring to Table B-1, columns one and four are the worst cases because they represent the highest aircraft velocity (110 knots). For these two columns then, conclusions of manuevering limitations can be drawn for MLS azimuth coverage of 20°, 40°, and 60°.

Using the reasoning above, the worst cases for 20° azimuth MLS coverage are shown on Figures B-1, B-4, B-7, B-10, B-13, B-16, B-19, and B-22. From these plots it is apparent that nominal paths should intersect the MLS at least 3/4 mile beyond the common path gate to assure that a successful approach can be made at any inbound heading.

The worst cases for 40° azimuth MLS coverage are shown on Figures B-25, B-28, B-31, and B-34. Except for cases of a one mile common path, aircraft could enter the MLS coverage short of the common path gate and execute an "S" turn onto the final path. The same is true for all of the 60° azimuth coverage cases.

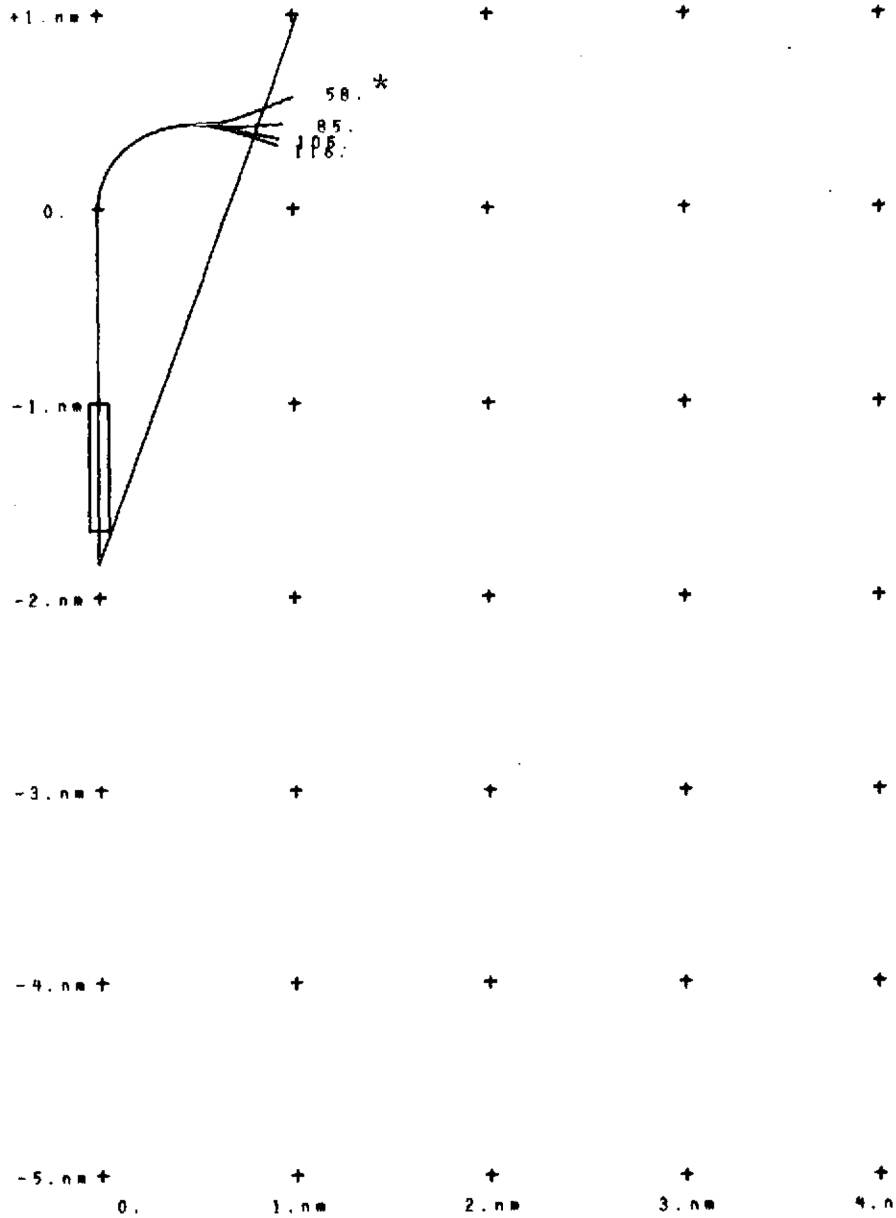
A final caution should be noted regarding the conclusions drawn above. The plots were made assuming a 4000 feet runway with the azimuth transmitter located 1000 feet beyond the stop end of the runway. The maneuvers shown assume that the aircraft is always operating in level flight against either bank or bank rate limits and that turns are started at exactly the right times. The initial turn is made one second after entering the coverage. The maneuvers shown are not practical, but represent worst case entries to MLS coverage from which the aircraft can recover without a go-around. Actual nominal paths should intersect the MLS coverage far enough from the azimuth antenna so that cross track uncertainties will provide little likelihood of requiring the maneuvers shown in this appendix.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-1. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

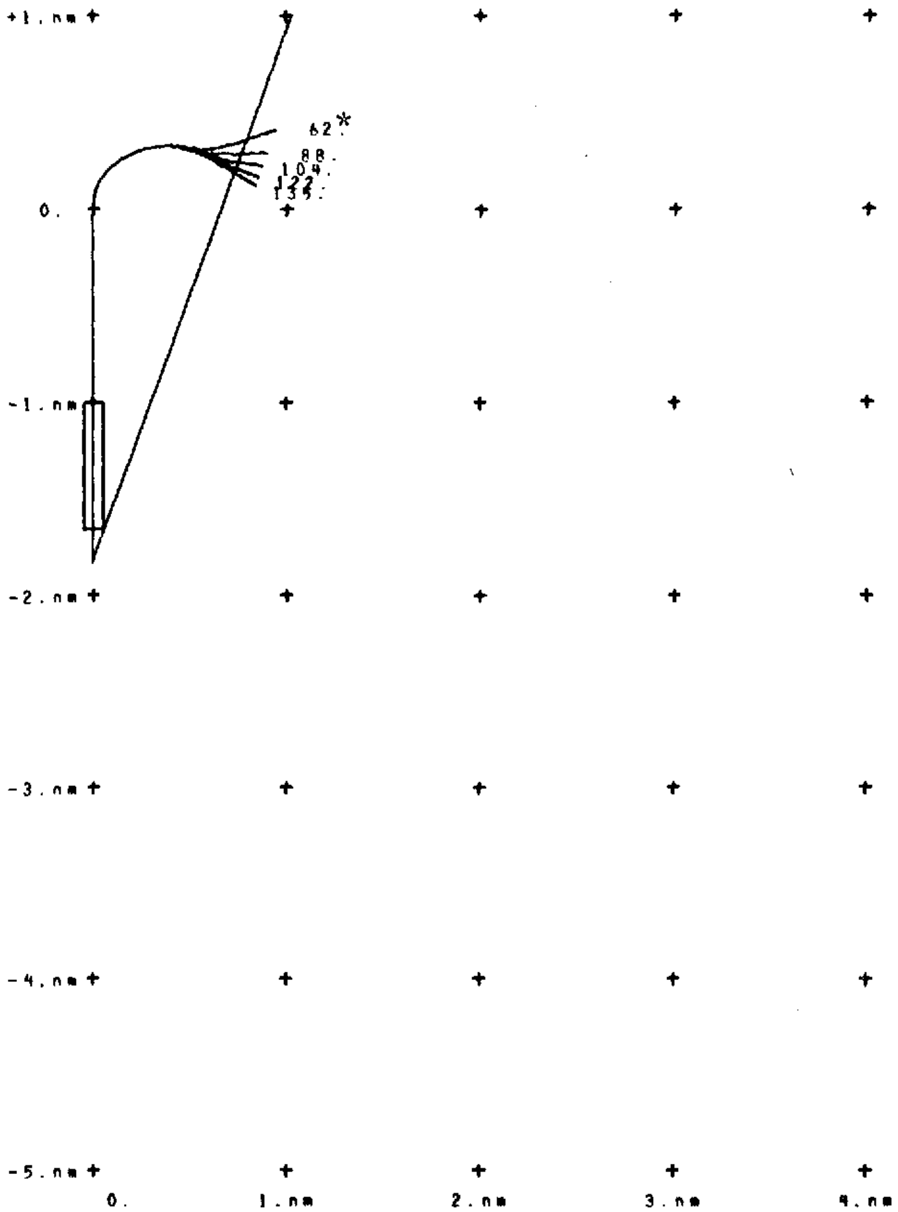
Common path length	=1. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=20. deg.
Aircraft bank angle limit	=25. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	=110. kn.
Wind velocity	=40. kn.
Wind direction	= 90. deg.



*Initial Inbound Aircraft Heading in degrees where the final heading is zero degrees.

FIGURE B-2. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length	=1. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=20. deg.
Aircraft bank angle limit	=25. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	= 95. kn.
Wind velocity	=40. kn.
Wind direction	= 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-3. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =1. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =20. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 80. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.

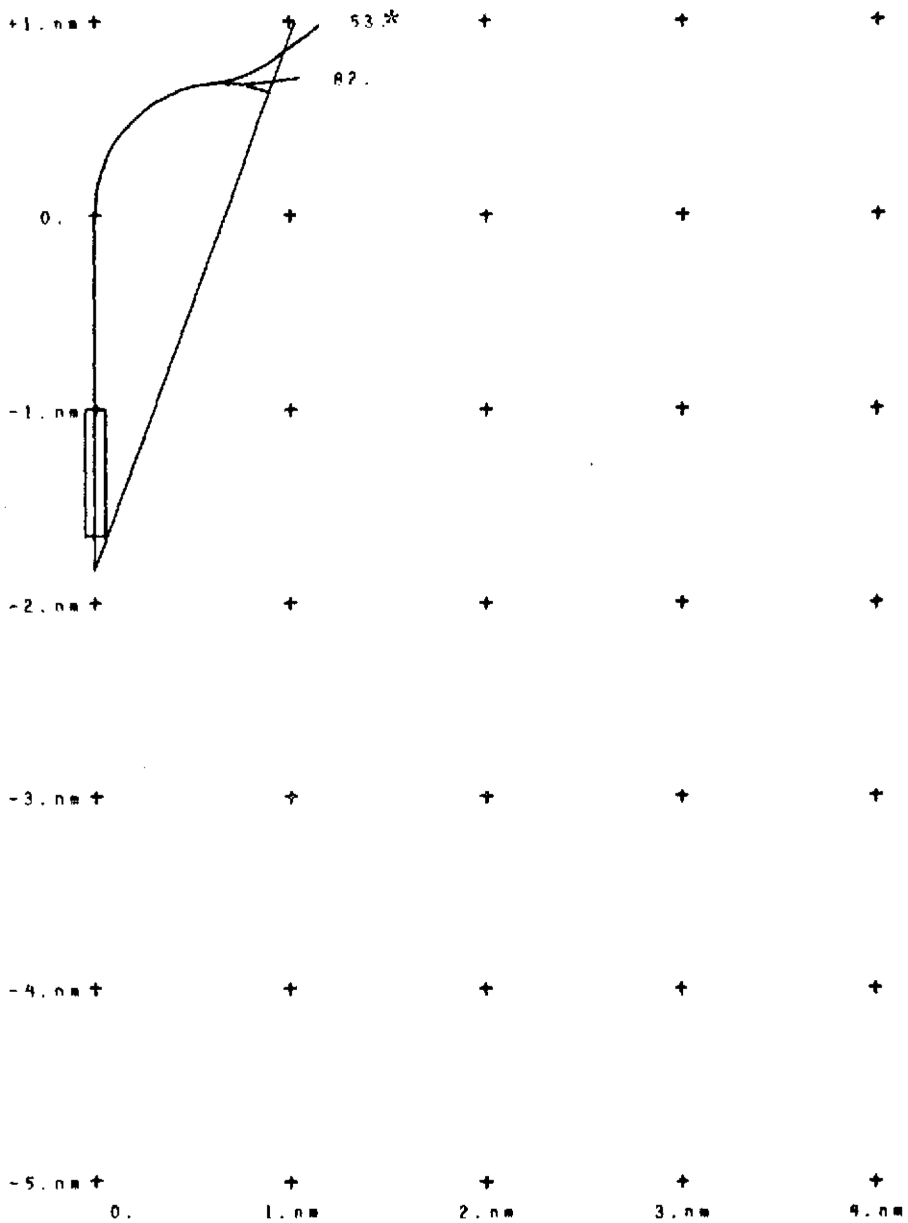
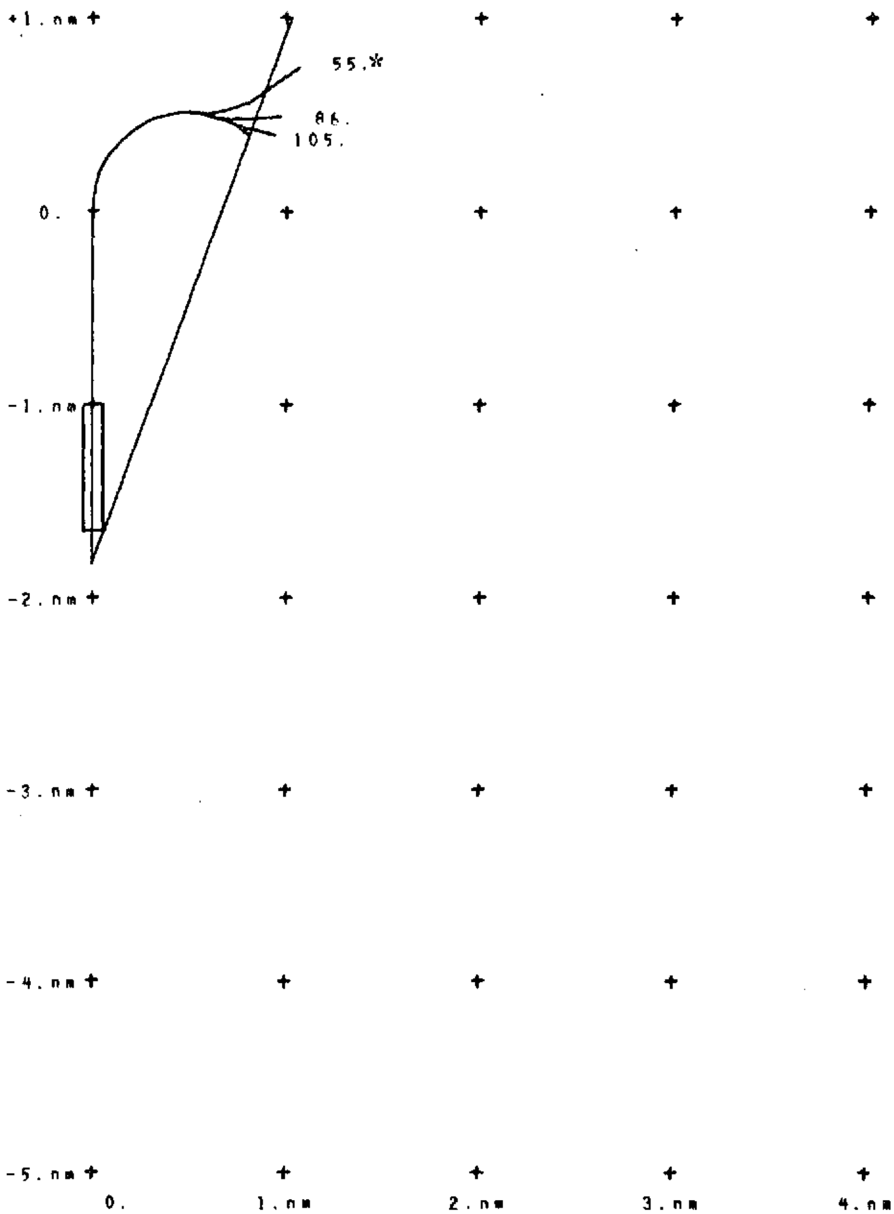


FIGURE B-4. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

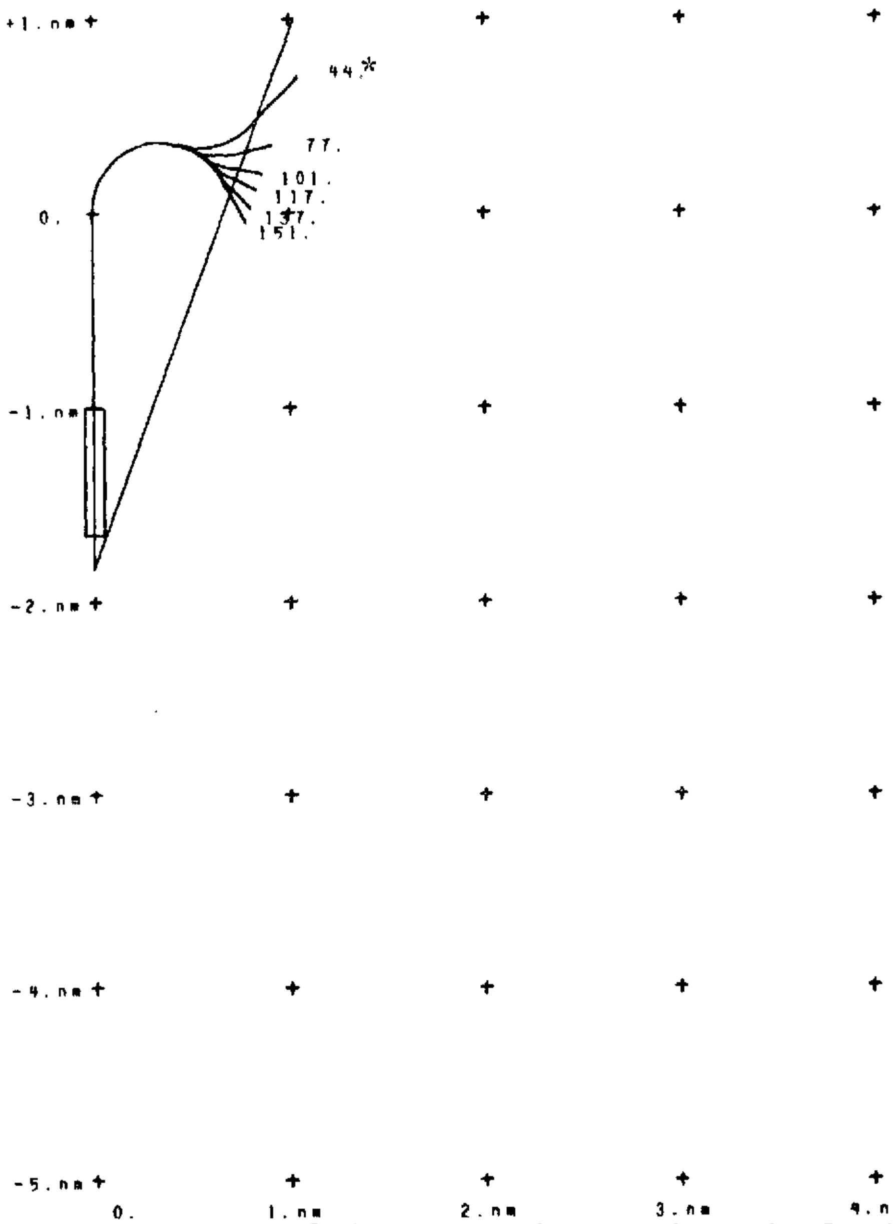
Common path length =1. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =20. deg.
Aircraft bank angle limit =15. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity =110. kn.
Wind velocity = 0. kn.
Wind direction = 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-5. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

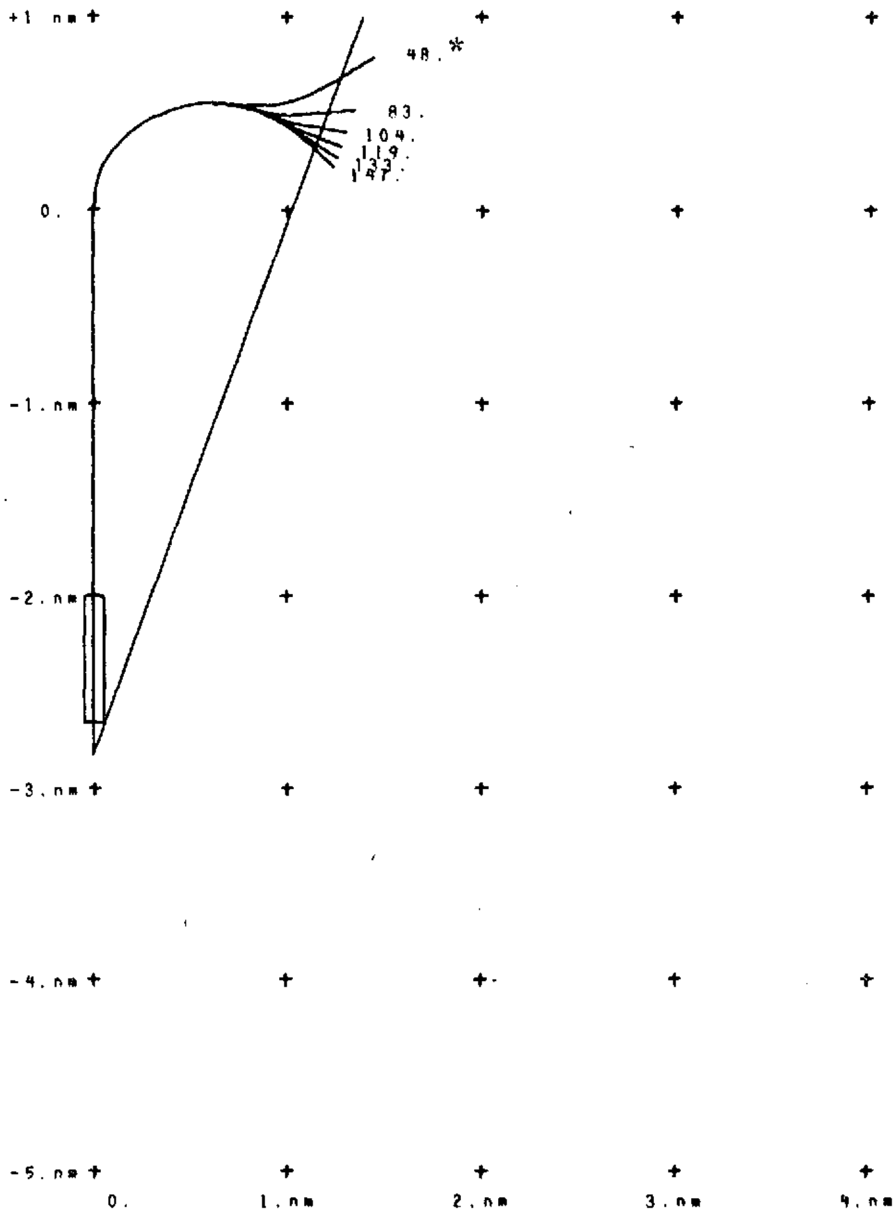
Common path length	=1. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=20. deg.
Aircraft bank angle limit	=15. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	= 95. kn.
Wind velocity	= 0. kn.
Wind direction	= 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-6. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

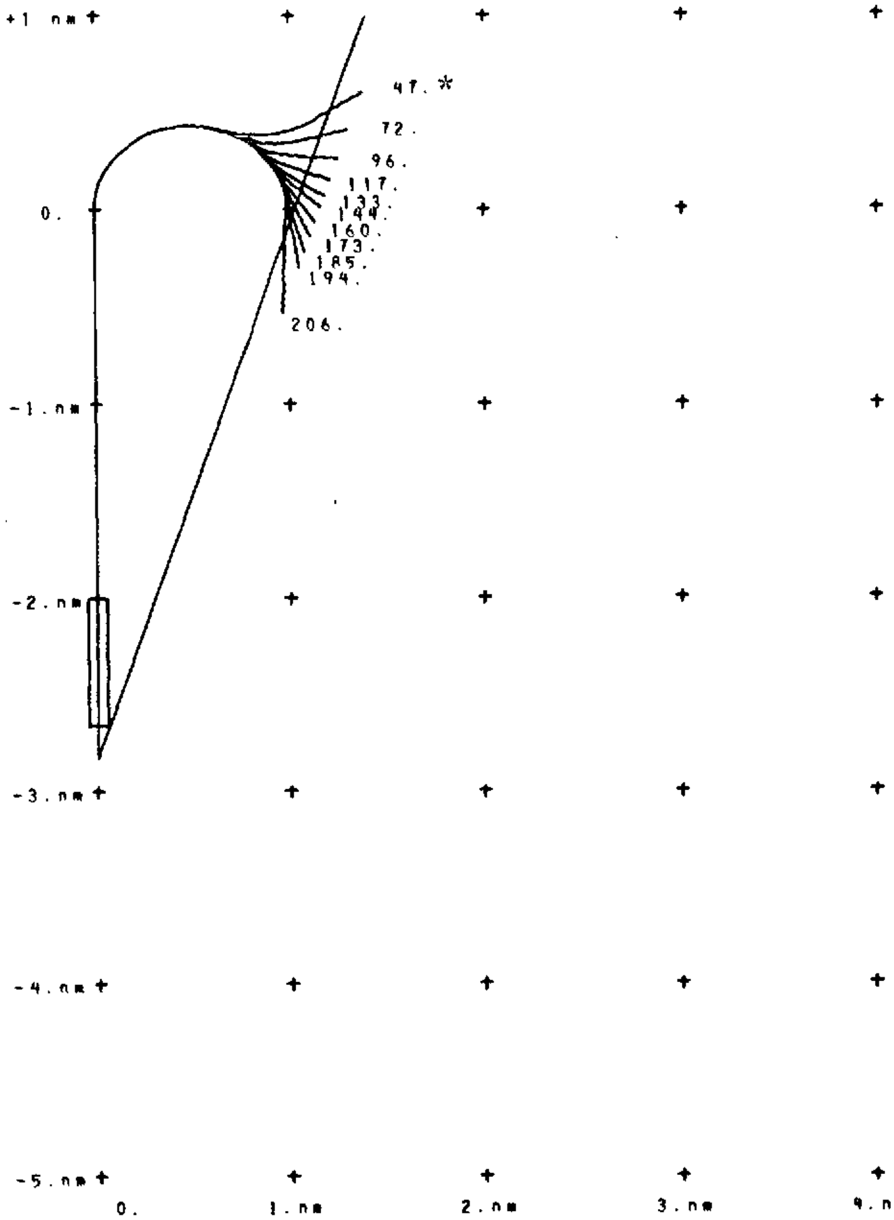
Common path length = 1. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway = 1000. ft.
MLS Azimuth angle = 20. deg.
Aircraft bank angle limit = 15. deg.
Aircraft bank angle rate limit = 10. deg./sec.
Aircraft velocity = 80. kn.
Wind velocity = 0. kn.
Wind direction = 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-7. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

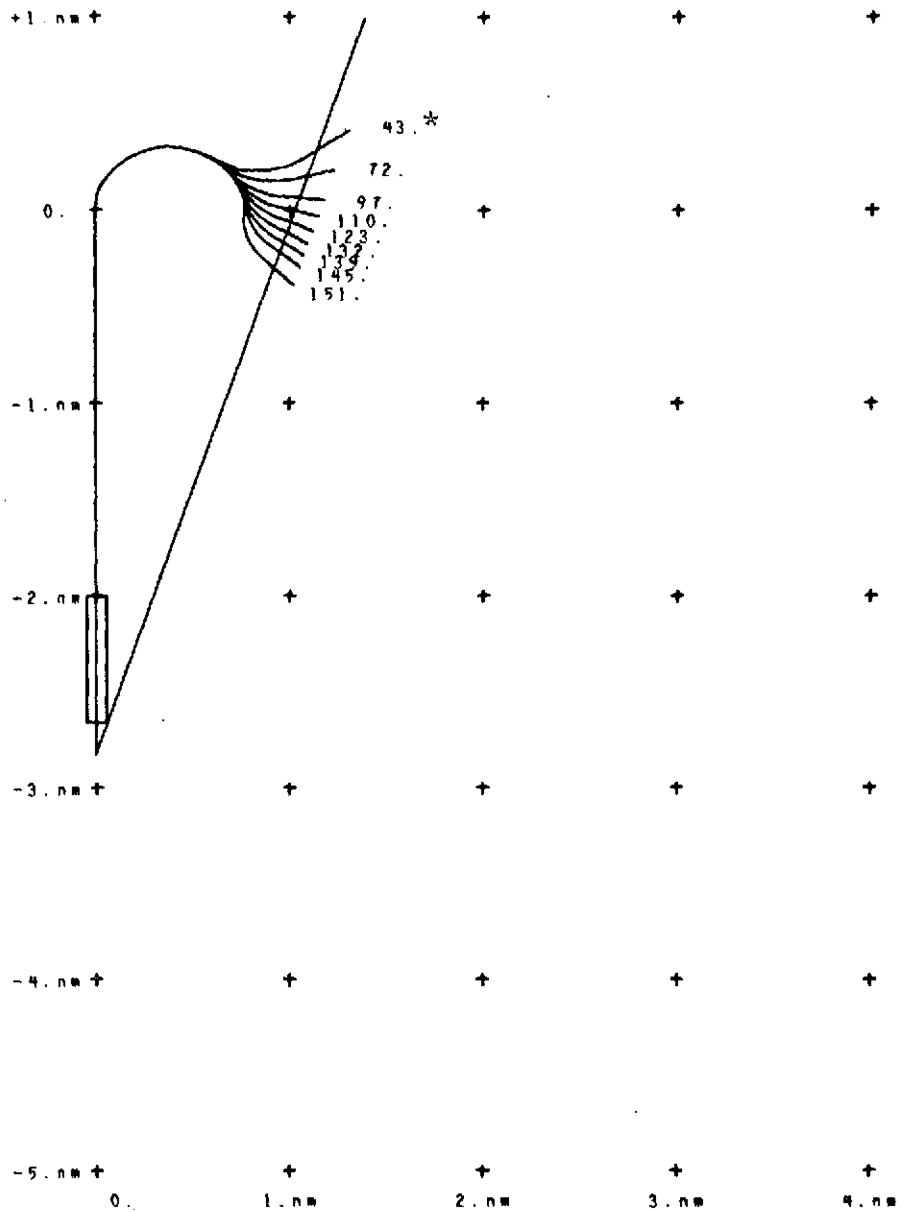
Common path length =2. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =20. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity =110. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-8. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

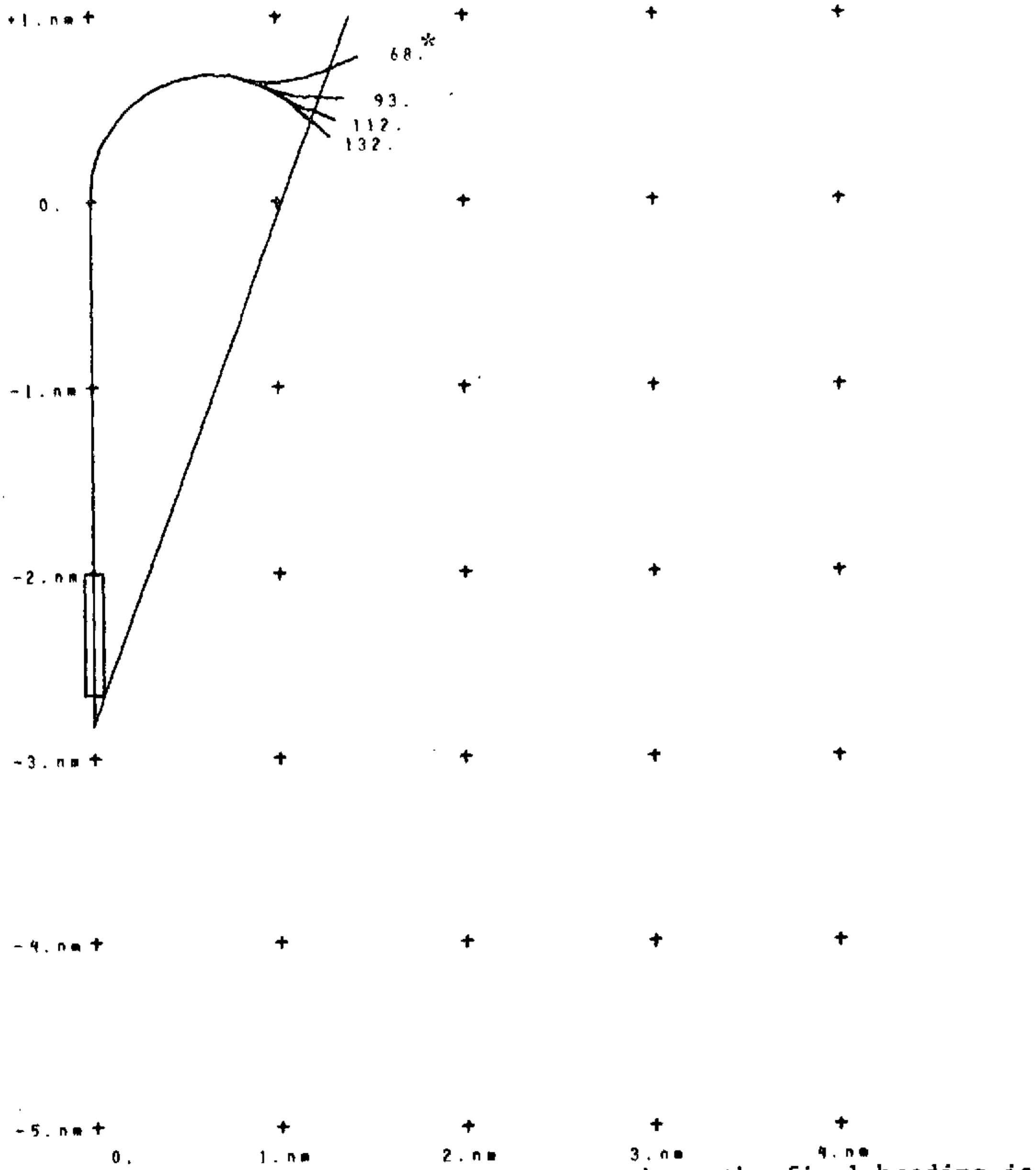
Common path length =2. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =20. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 95. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-9. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

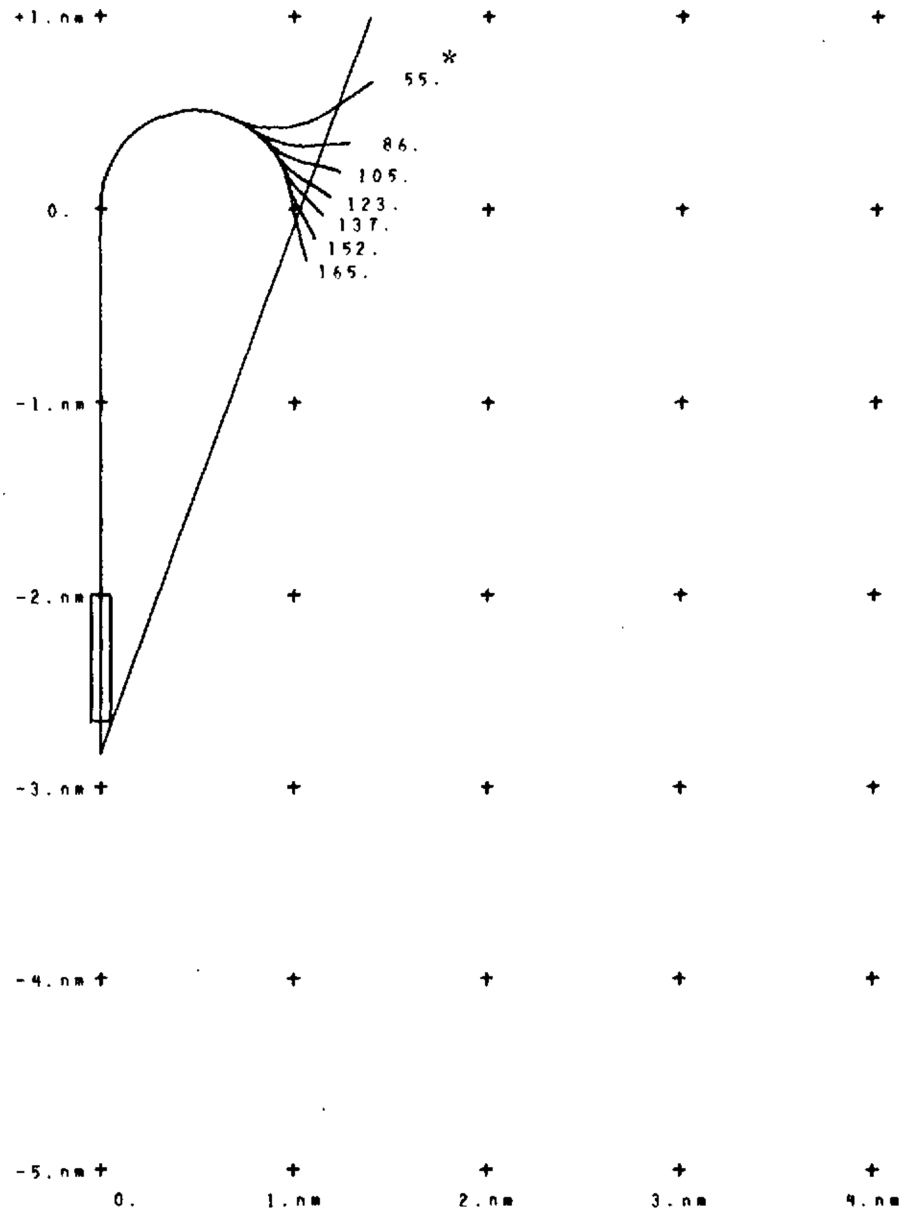
Common path length	=2. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=20. deg.
Aircraft bank angle limit	=25. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	= 80. kn.
Wind velocity	=40. kn.
Wind direction	= 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-10. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

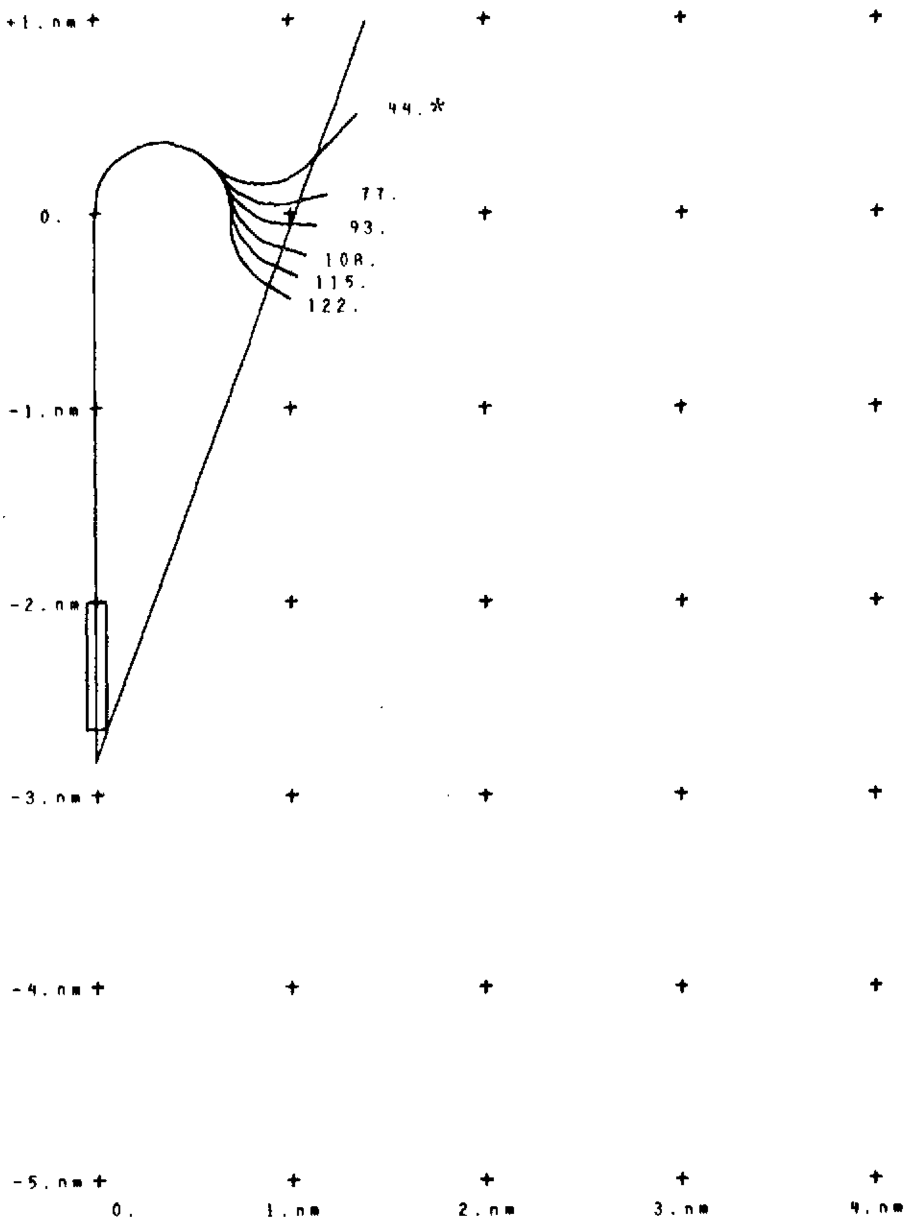
Common path length	=2. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=20. deg.
Aircraft bank angle limit	=15. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	=110. kn.
Wind velocity	= 0. kn.
Wind direction	= 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-11. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

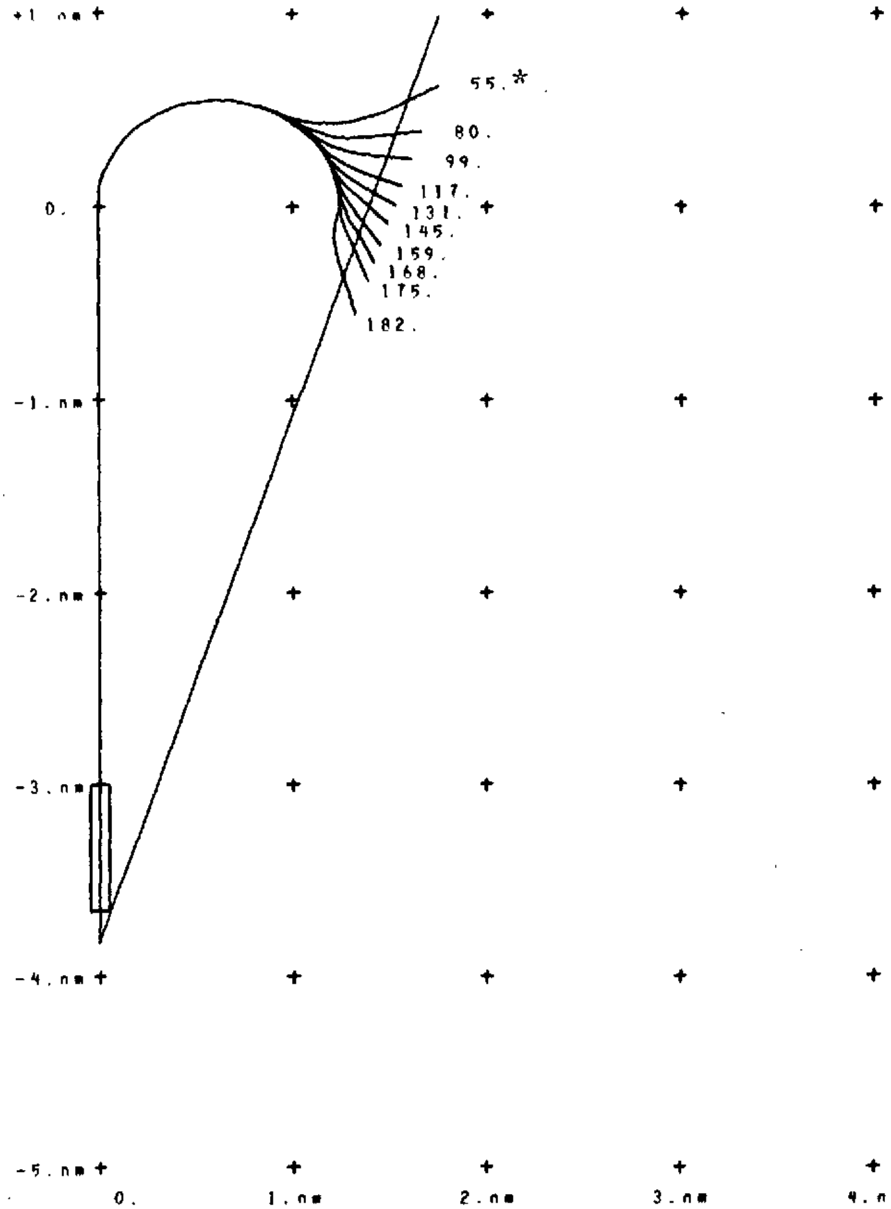
Common path length	=2. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=20. deg.
Aircraft bank angle limit	=15. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	= 95. kn.
Wind velocity	= 0. kn.
Wind direction	= 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-12. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

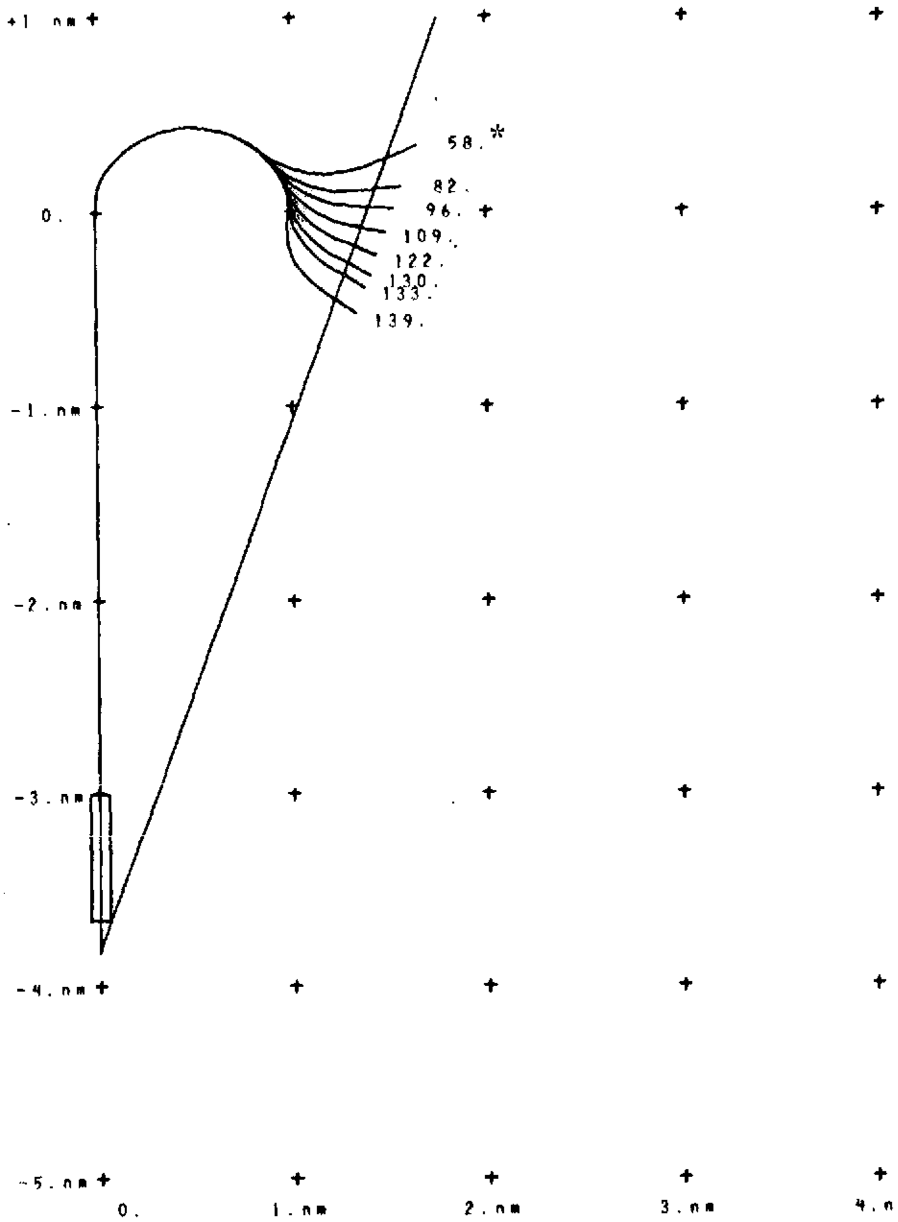
Common path length	=2. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=20. deg.
Aircraft bank angle limit	=15. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	= 80. kn.
Wind velocity	= 0. kn.
Wind direction	= 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-13. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

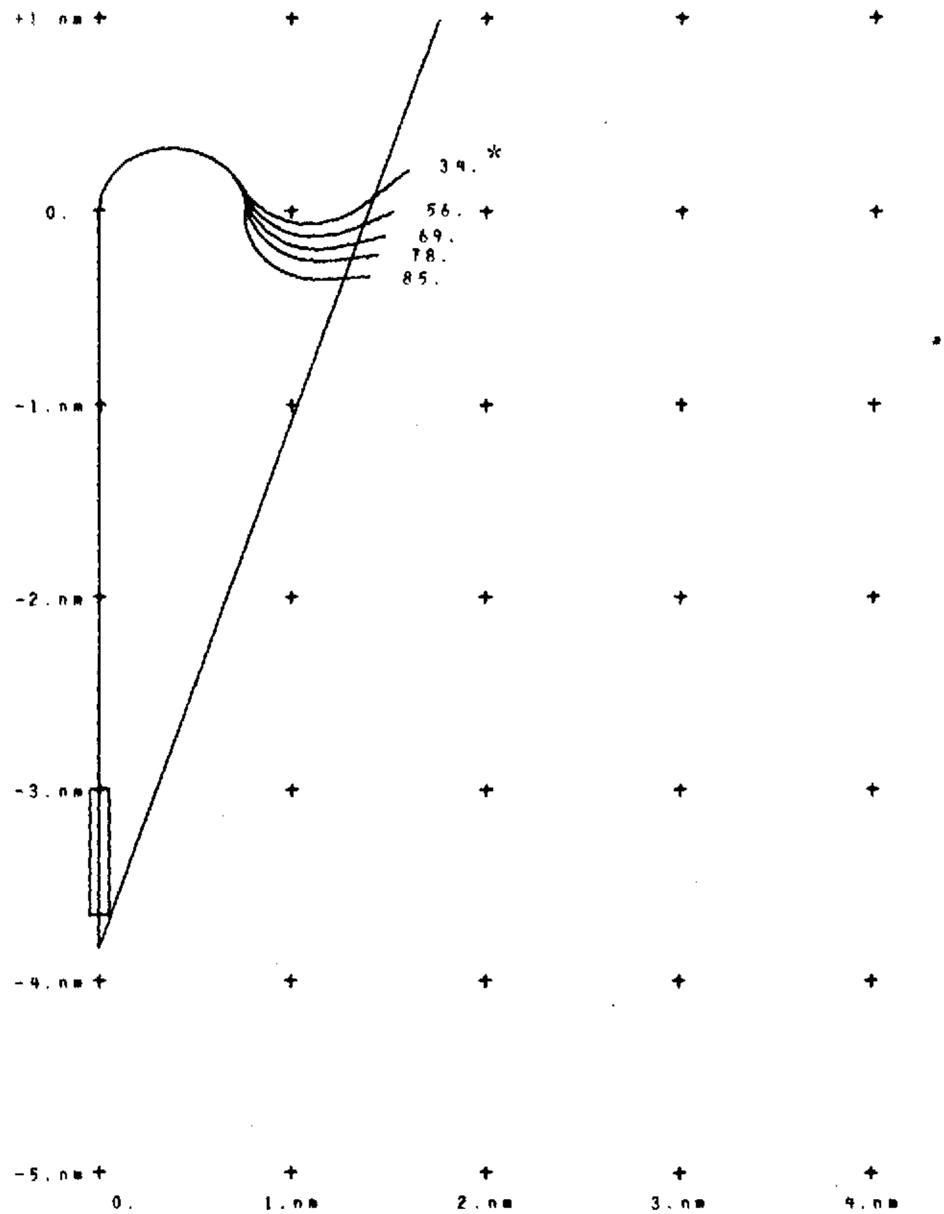
Common path length = 3. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway = 1000. ft.
MLS Azimuth angle = 20. deg.
Aircraft bank angle limit = 25. deg.
Aircraft bank angle rate limit = 10. deg./sec.
Aircraft velocity = 110. kn.
Wind velocity = 40. kn.
Wind direction = 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-14. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

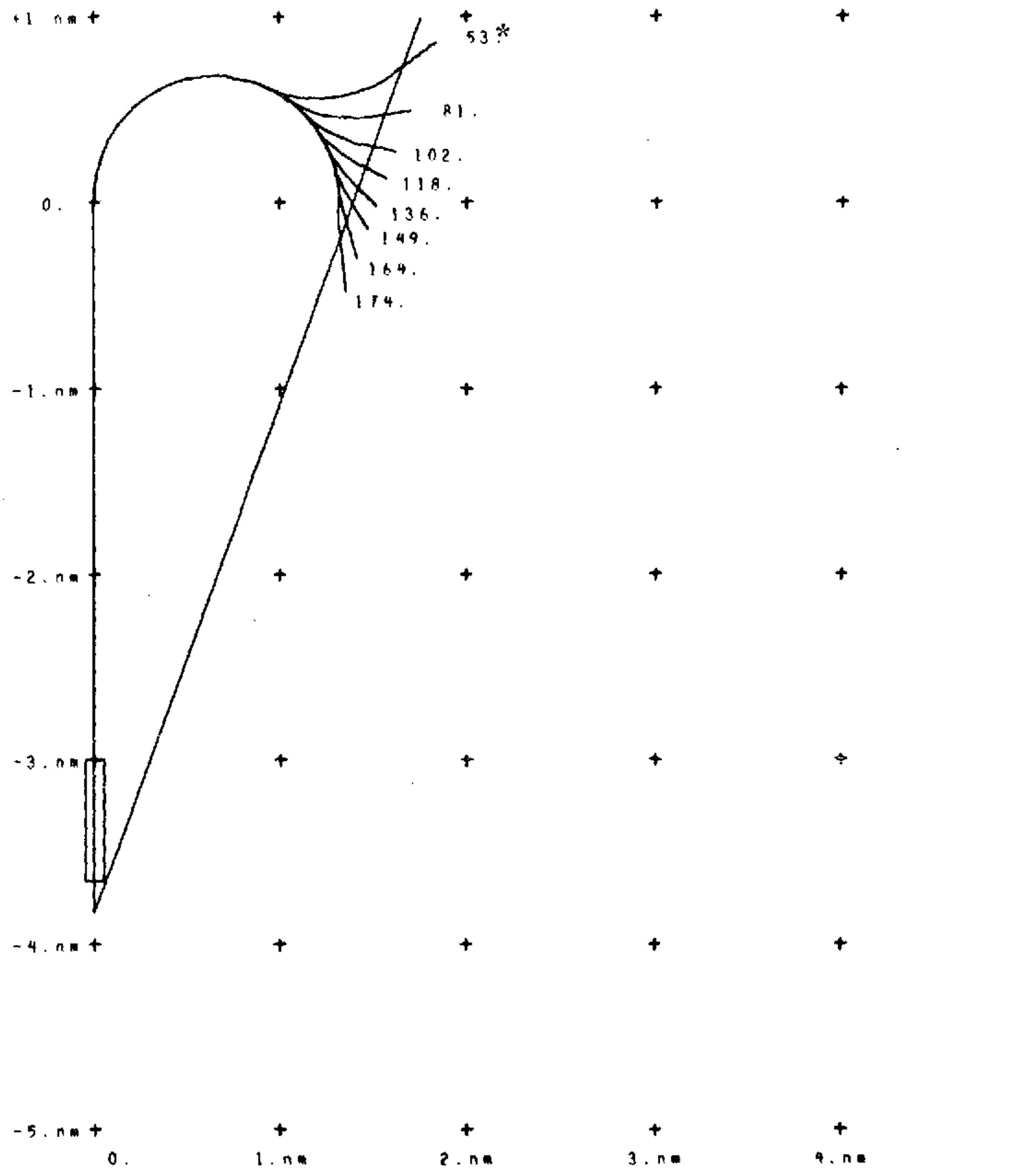
Common path length = 3. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway = 1000. ft.
MLS Azimuth angle = 20. deg.
Aircraft bank angle limit = 25. deg.
Aircraft bank angle rate limit = 10. deg./sec.
Aircraft velocity = 95. kn.
Wind velocity = 40. kn.
Wind direction = 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-15. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

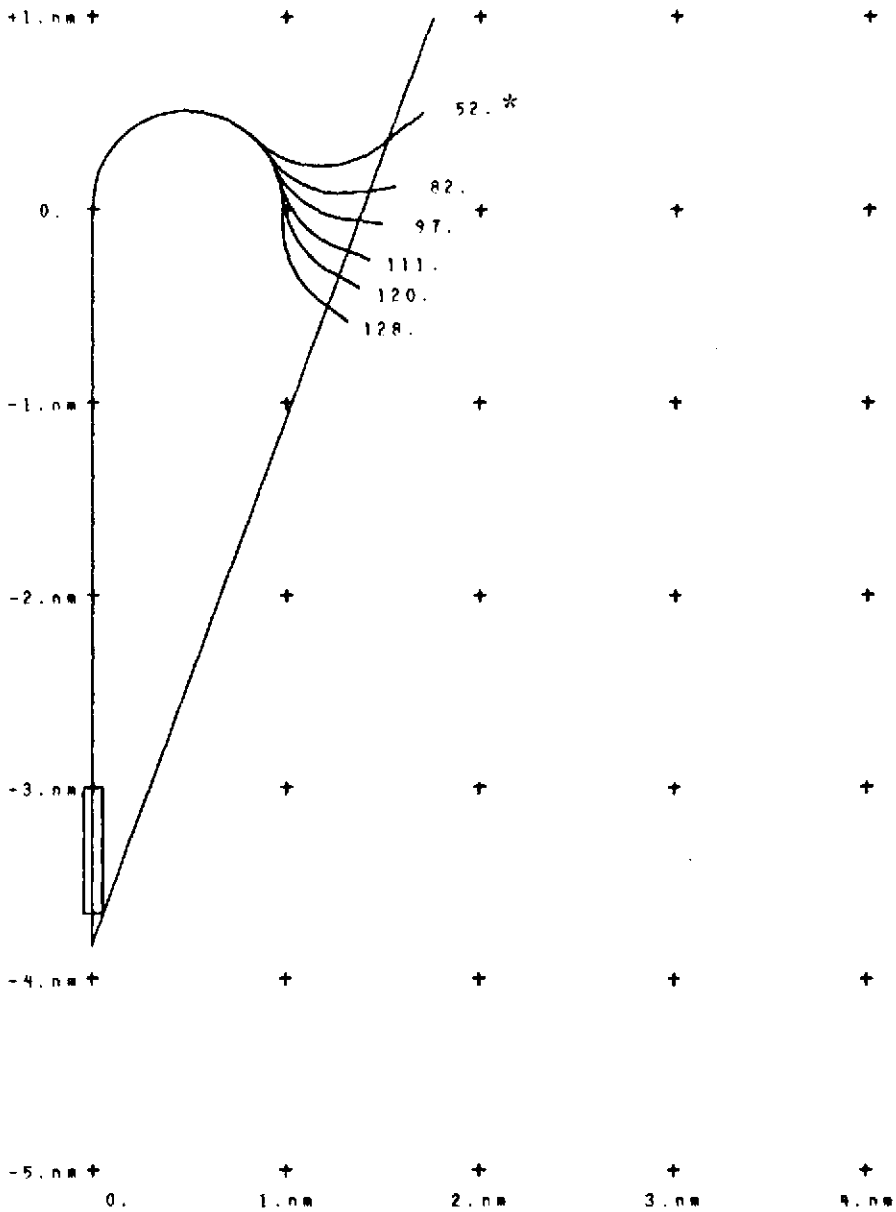
Common path length	=3. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=20. deg.
Aircraft bank angle limit	=25. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	= 80. kn.
Wind velocity	=40. kn.
Wind direction	= 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-16. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

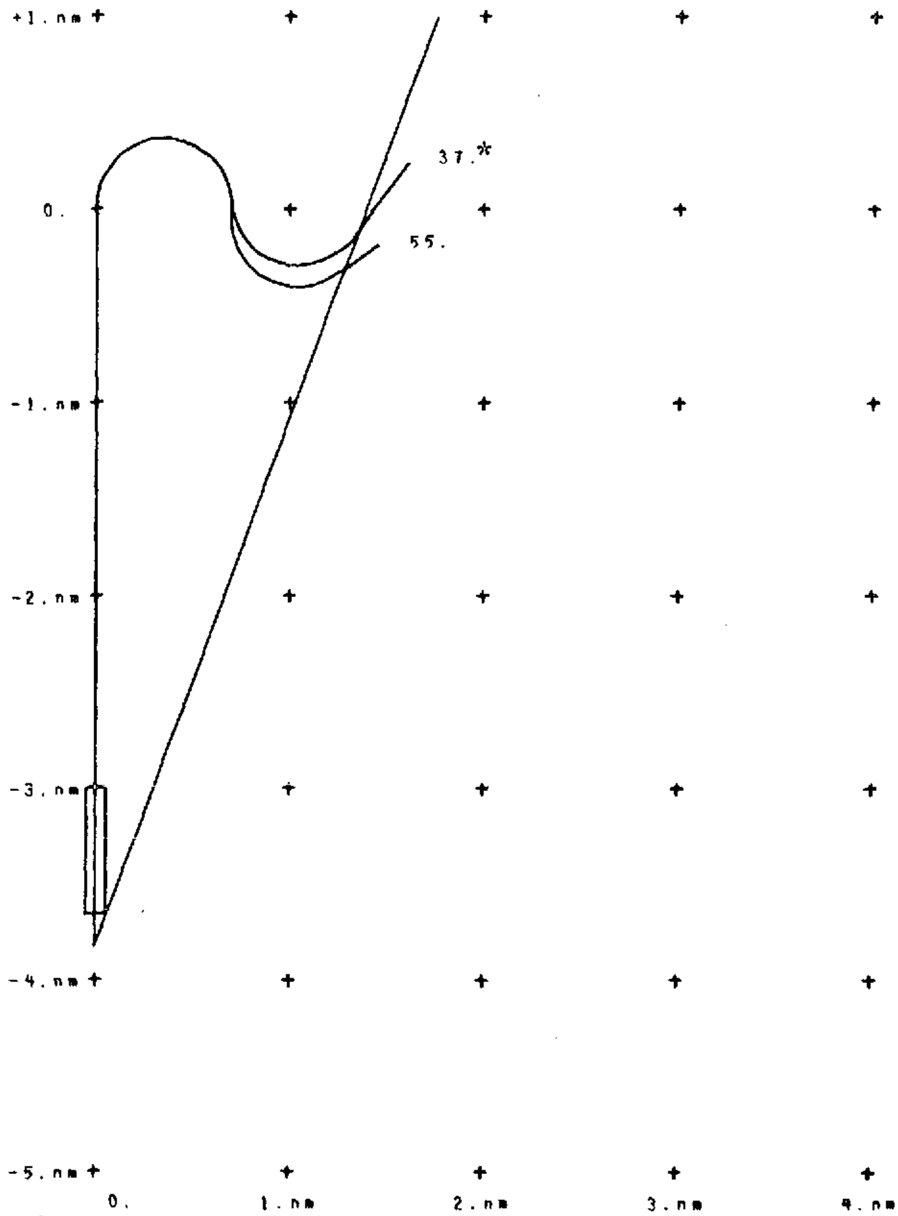
Common path length =3. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =20. deg.
Aircraft bank angle limit =15. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity =110. kn.
Wind velocity = 0. kn.
Wind direction = 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-17. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

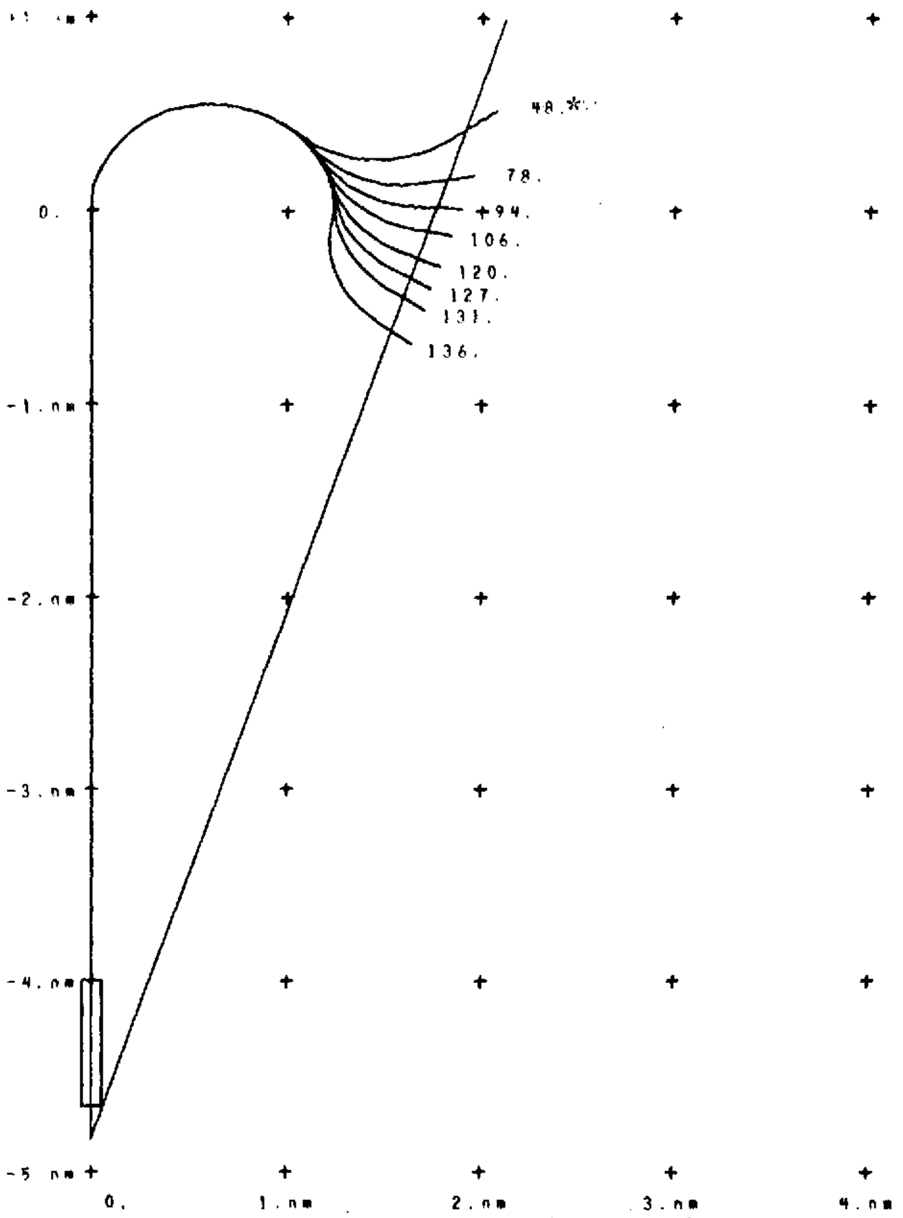
Common path length =3. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =20. deg.
Aircraft bank angle limit =15. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 95. kn.
Wind velocity = 0. kn.
Wind direction = 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-18. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

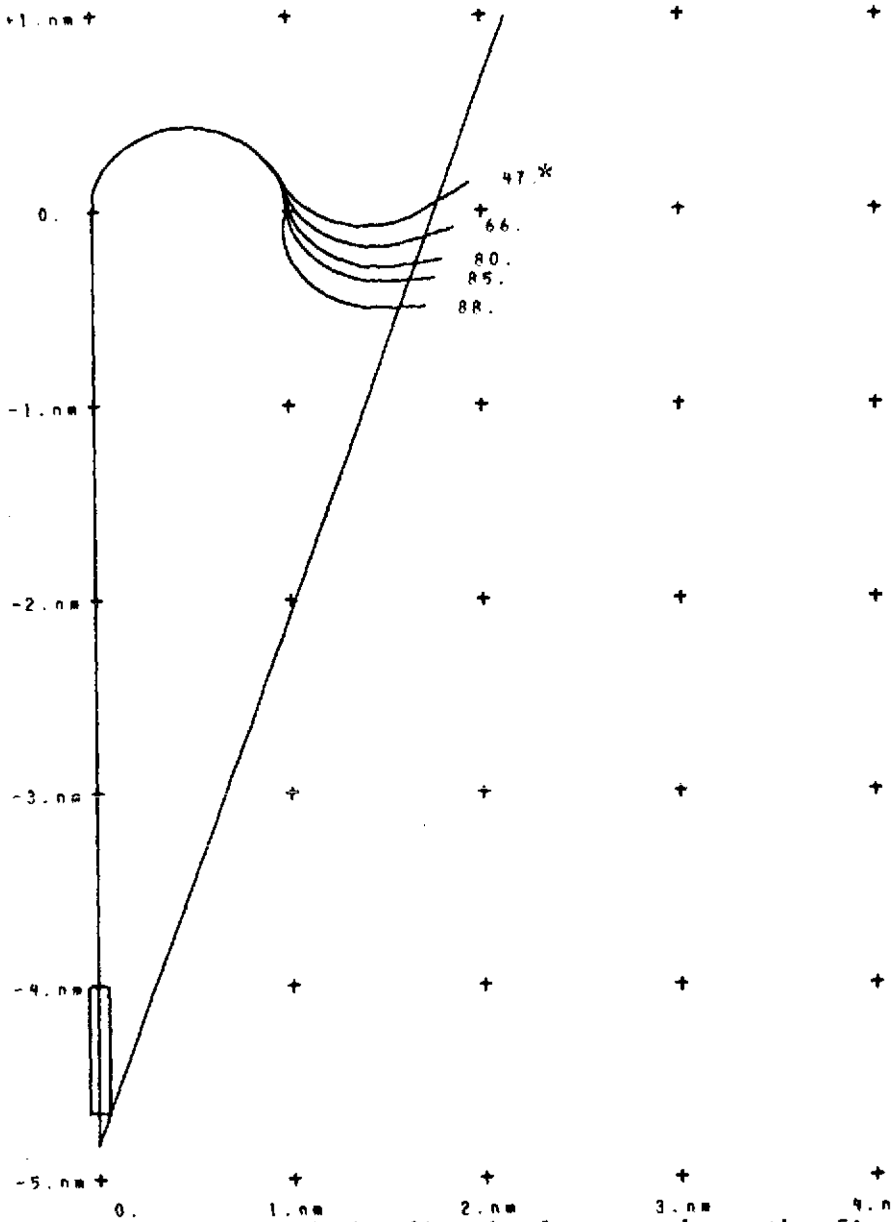
Common path length =3. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =20. deg.
Aircraft bank angle limit =15. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 80. kn.
Wind velocity = 0. kn.
Wind direction = 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-19. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =4. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =20. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity =110. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-20. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length	=4. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=20. deg.
Aircraft bank angle limit	=25. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	= 95. kn.
Wind velocity	=40. kn.
Wind direction	= 90. deg.

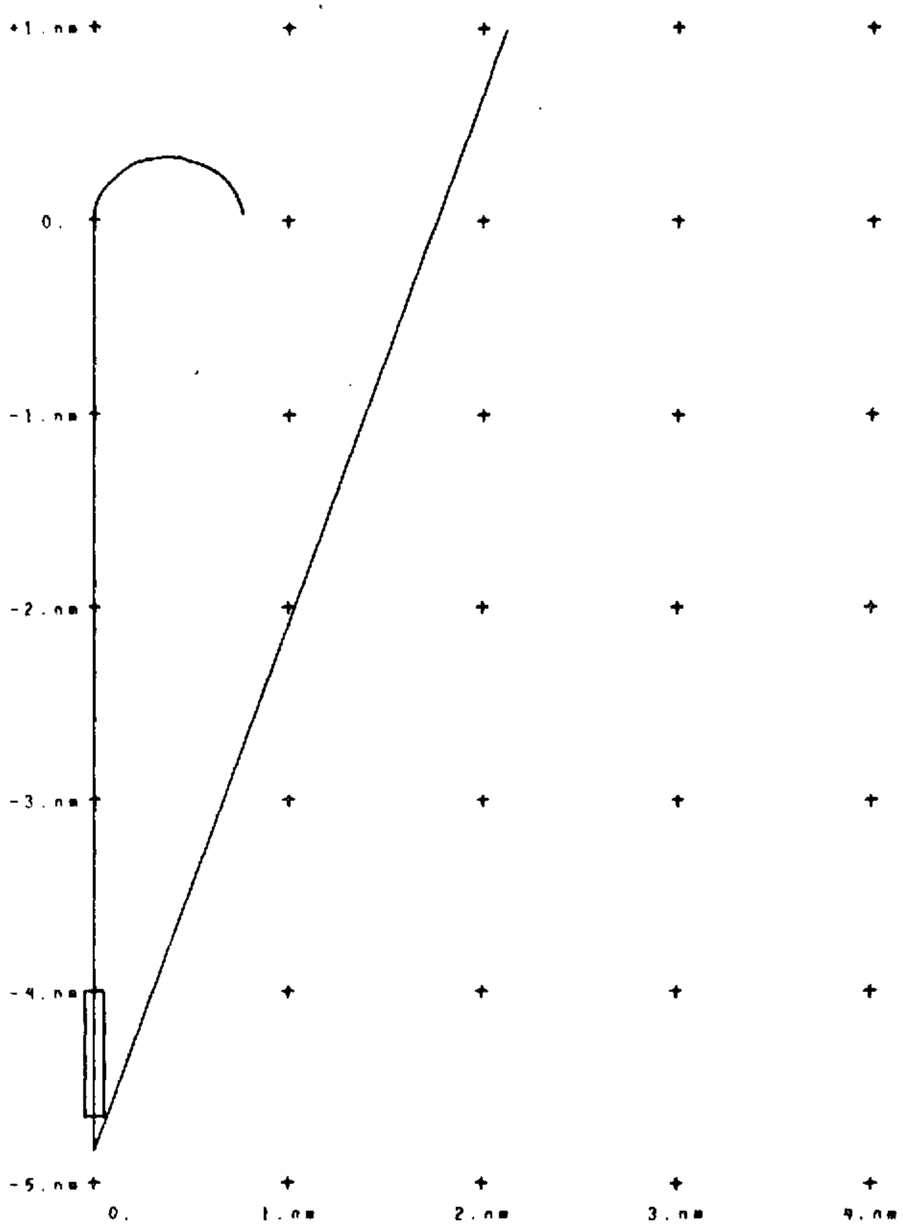
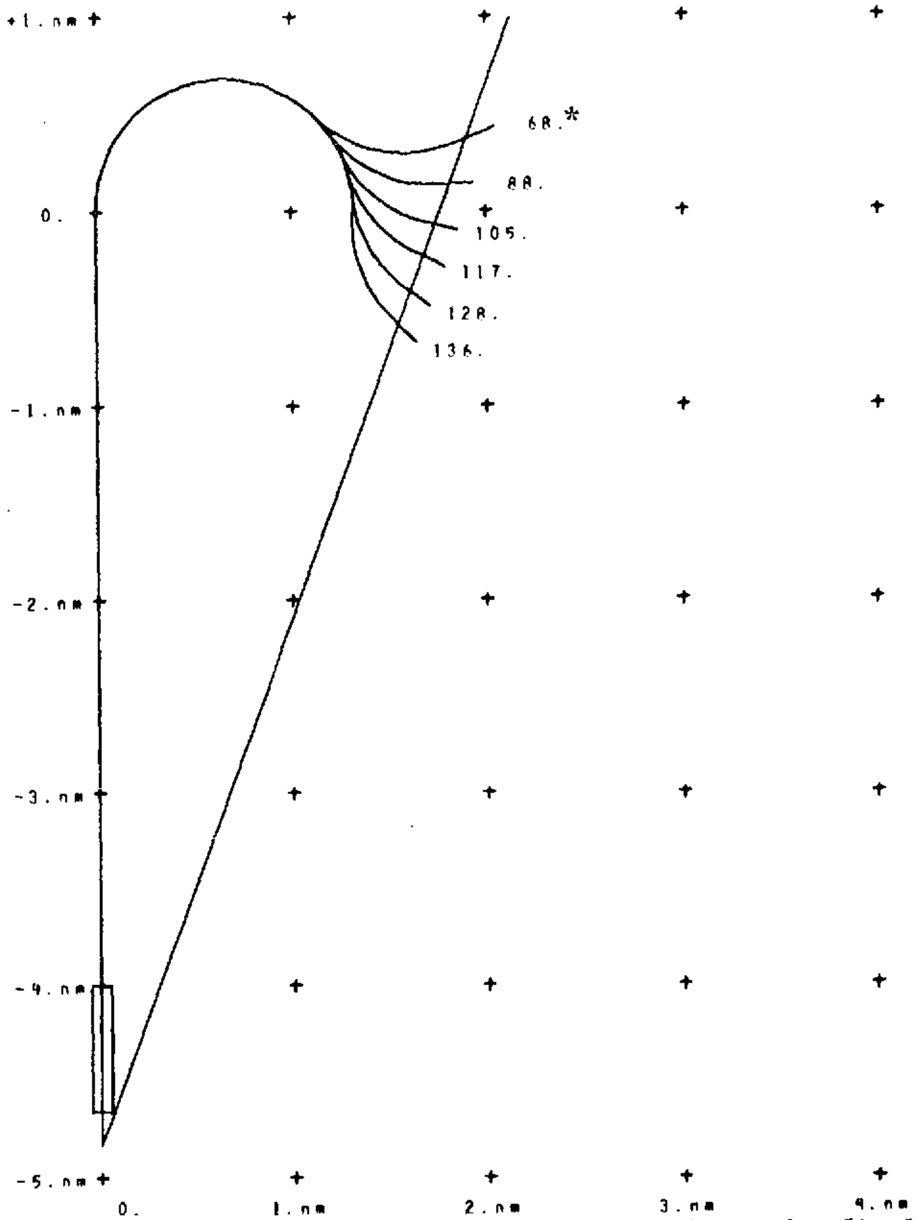


FIGURE B-21. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

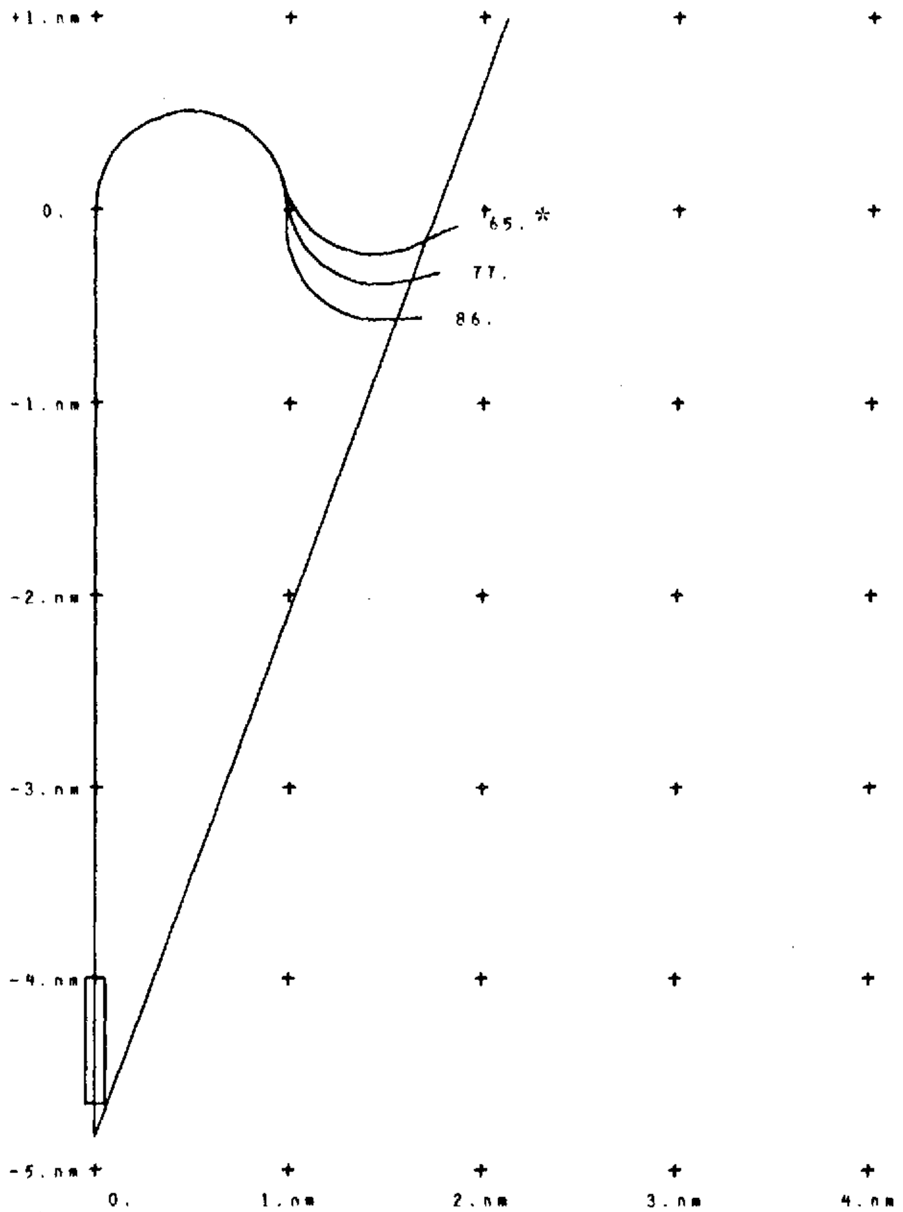
Common path length =4. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =20. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 80. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-22. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length	=4. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=20. deg.
Aircraft bank angle limit	=15. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	=110. kn.
Wind velocity	= 0. kn.
Wind direction	= 0. deg.



* Initial Inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-23. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length	=4. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=20. deg.
Aircraft bank angle limit	=15. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	= 95. kn.
Wind velocity	= 0. kn.
Wind direction	= 0. deg.

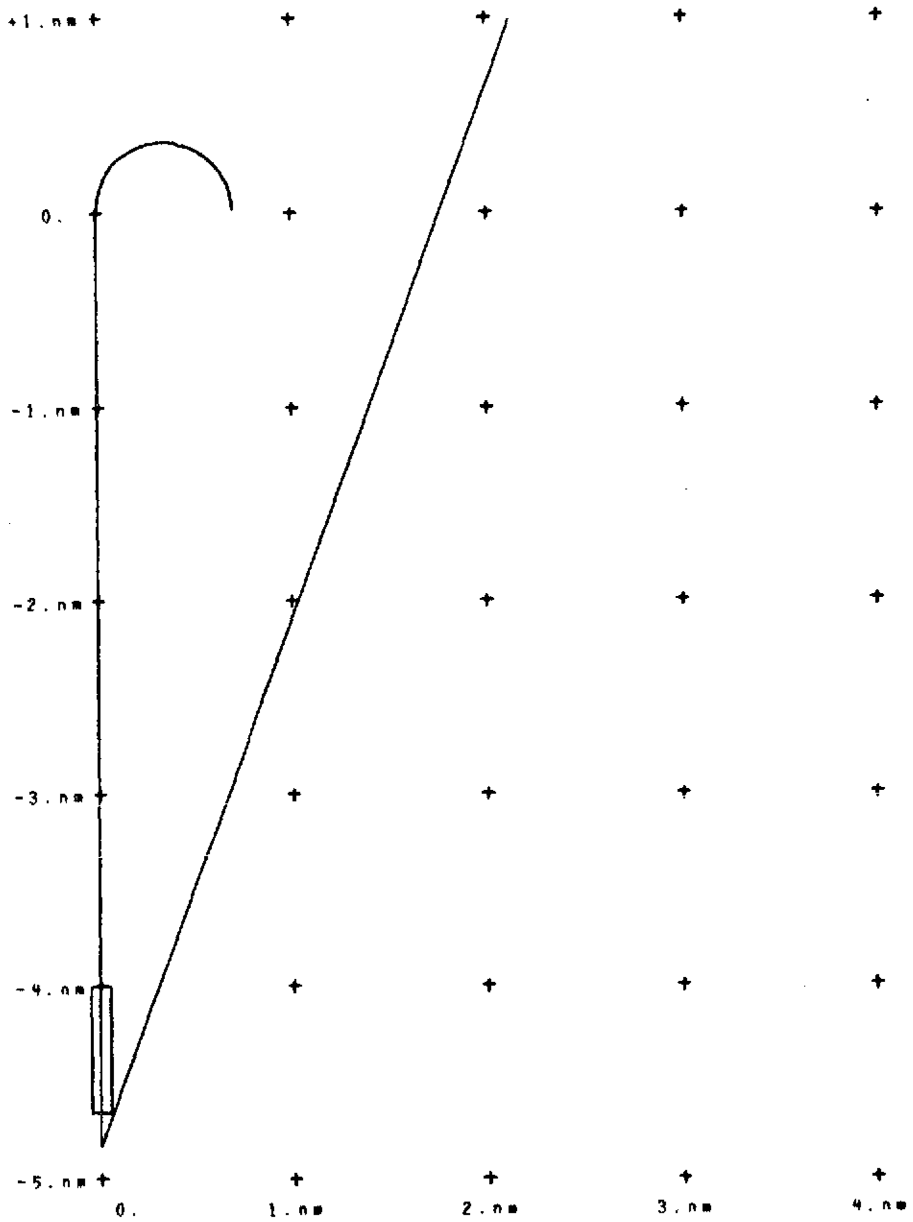
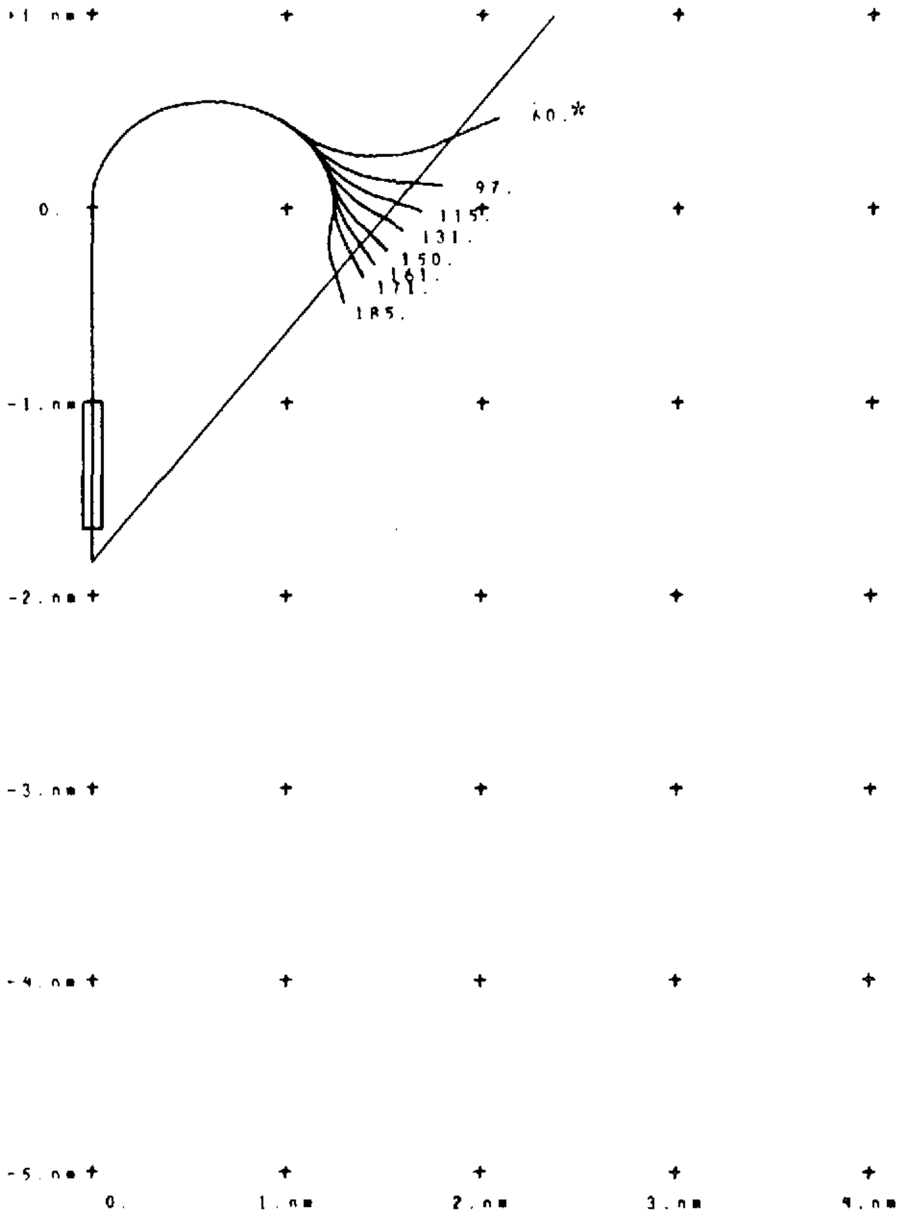


FIGURE B-24. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

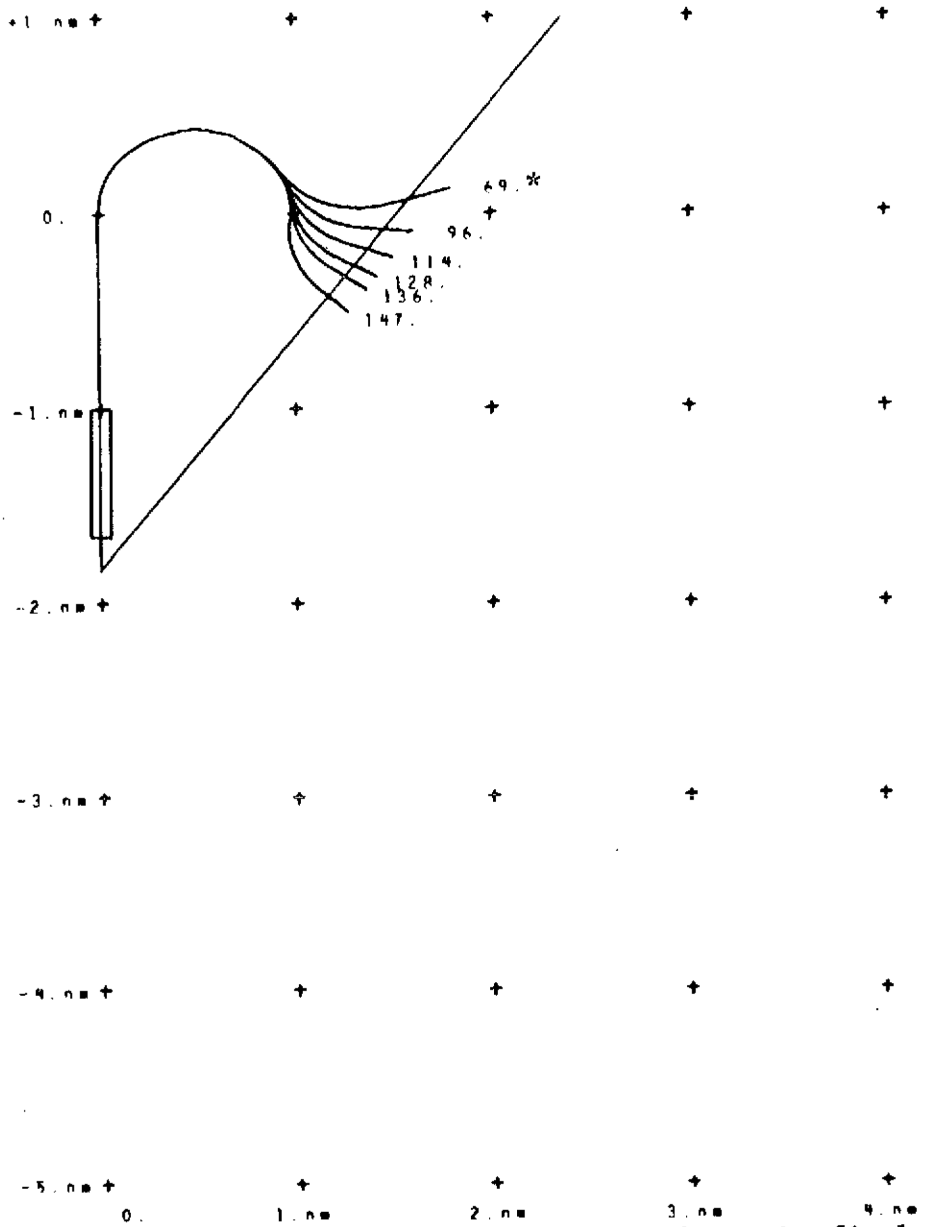
Common path length	=4.	nm.
Runway length	= 4000.	ft.
Azimuth siting beyond stop end of runway	=1000.	ft.
MLS Azimuth angle	=20.	deg.
Aircraft bank angle limit	=15.	deg.
Aircraft bank angle rate limit	=10.	deg./sec.
Aircraft velocity	= 80.	kn.
Wind velocity	= 0.	kn.
Wind direction	= 0.	deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-25. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

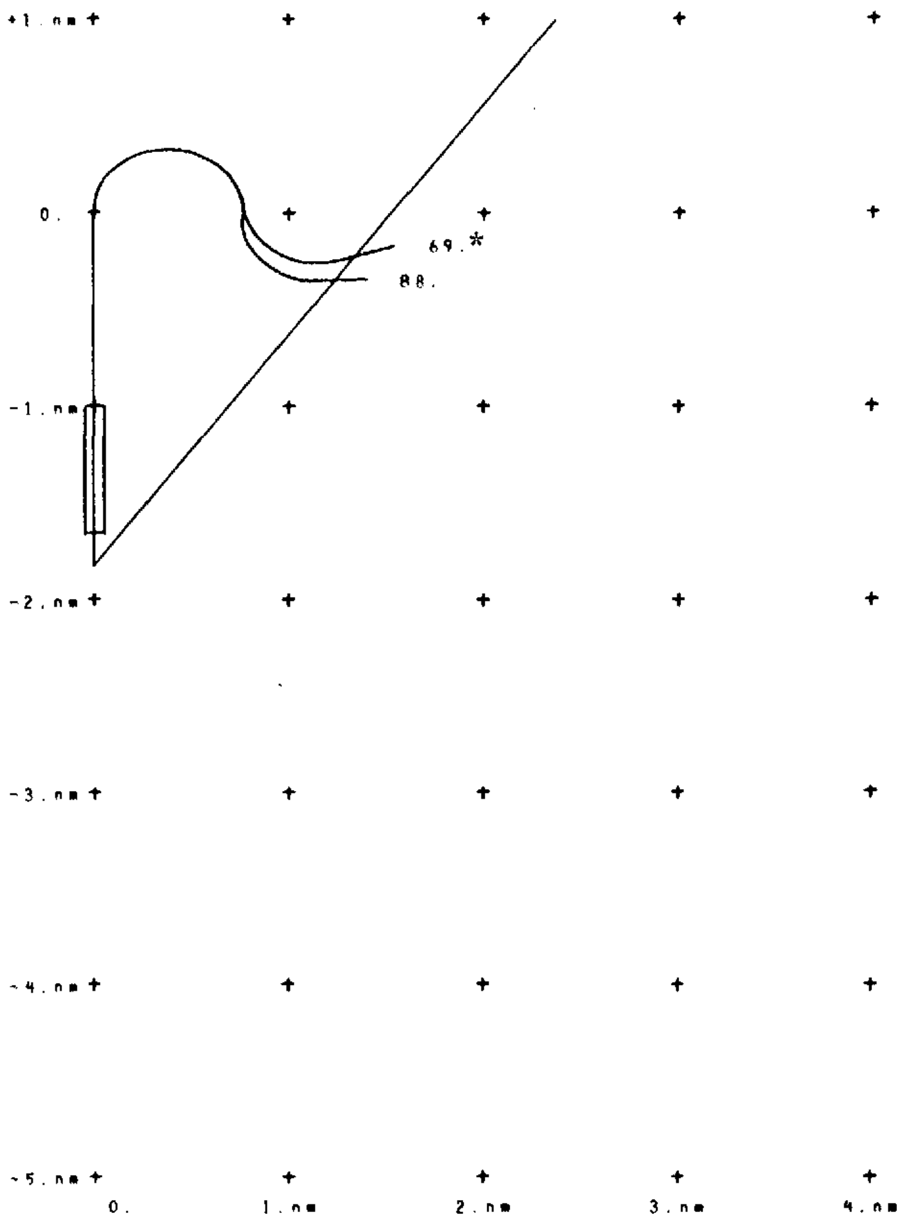
Common path length =1. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity =110. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-26. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

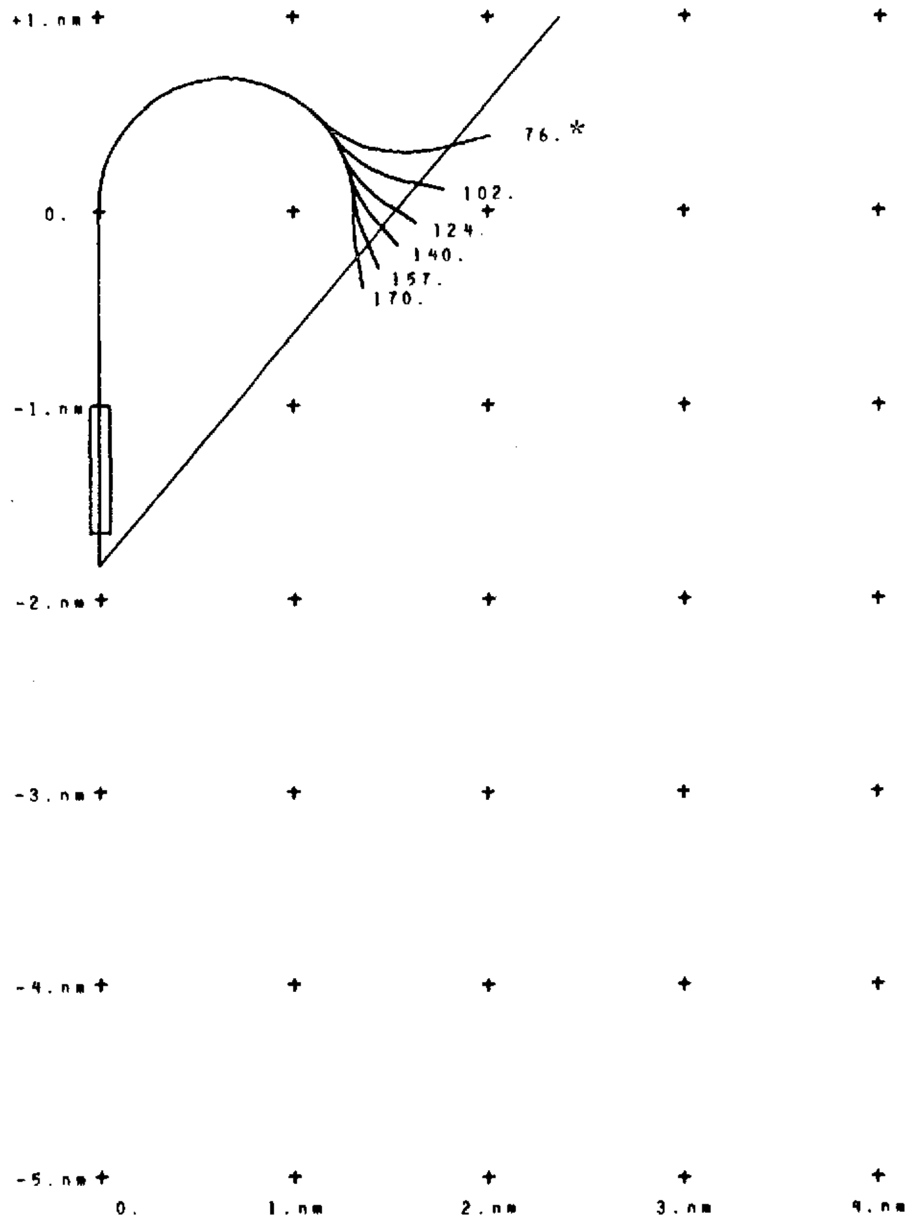
Common path length	=1. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=40. deg.
Aircraft bank angle limit	=25. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	= 95. kn.
Wind velocity	=40. kn.
Wind direction	= 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-27. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

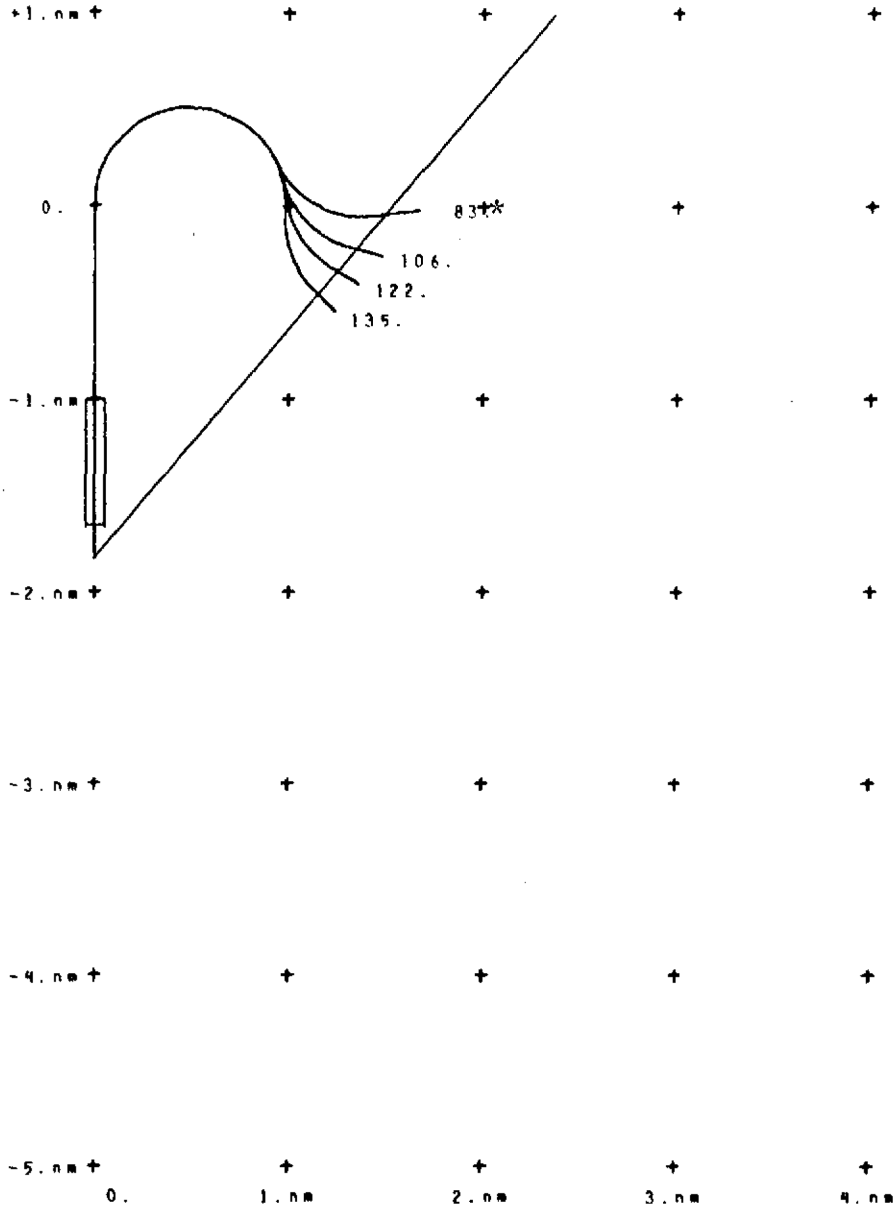
Common path length =1. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 80. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-28. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

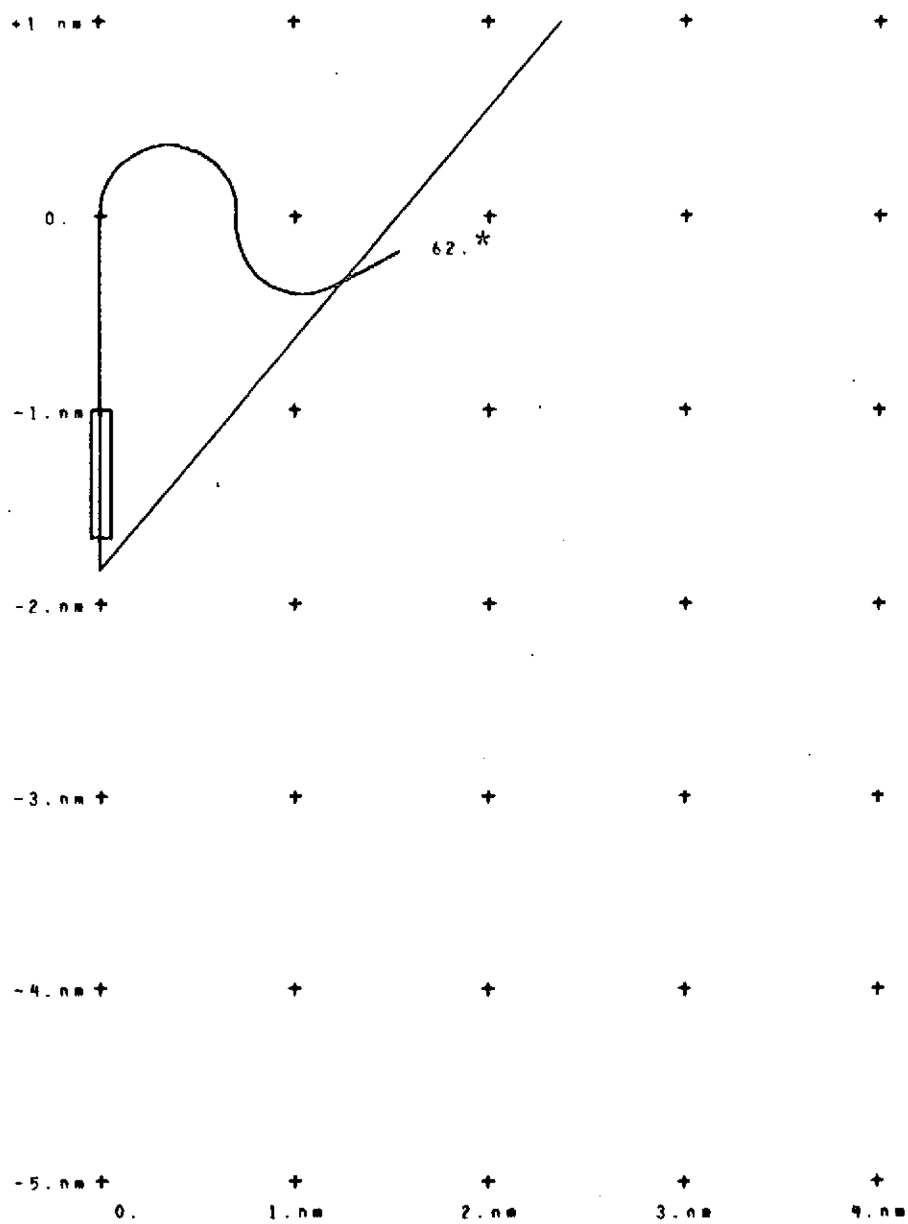
Common path length	=1. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=40. deg.
Aircraft bank angle limit	=15. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	=110. kn.
Wind velocity	= 0. kn.
Wind direction	= 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-29. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

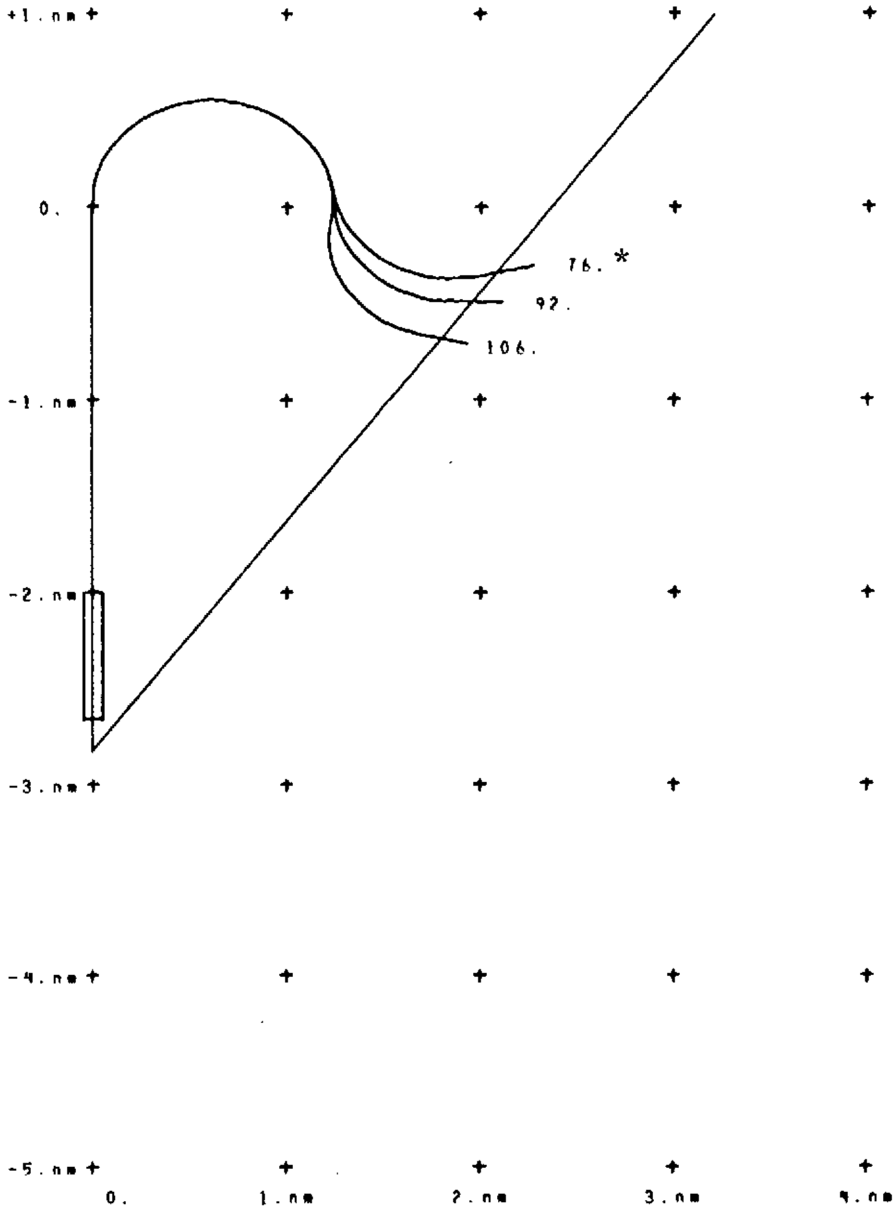
Common path length = 1. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway = 1000. ft.
MLS Azimuth angle = 40. deg.
Aircraft bank angle limit = 15. deg.
Aircraft bank angle rate limit = 10. deg./sec.
Aircraft velocity = 95. kn.
Wind velocity = 0. kn.
Wind direction = 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-30. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =1. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =15. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 80. kn.
Wind velocity = 0. kn.
Wind direction = 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-31. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =2. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity =110. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.

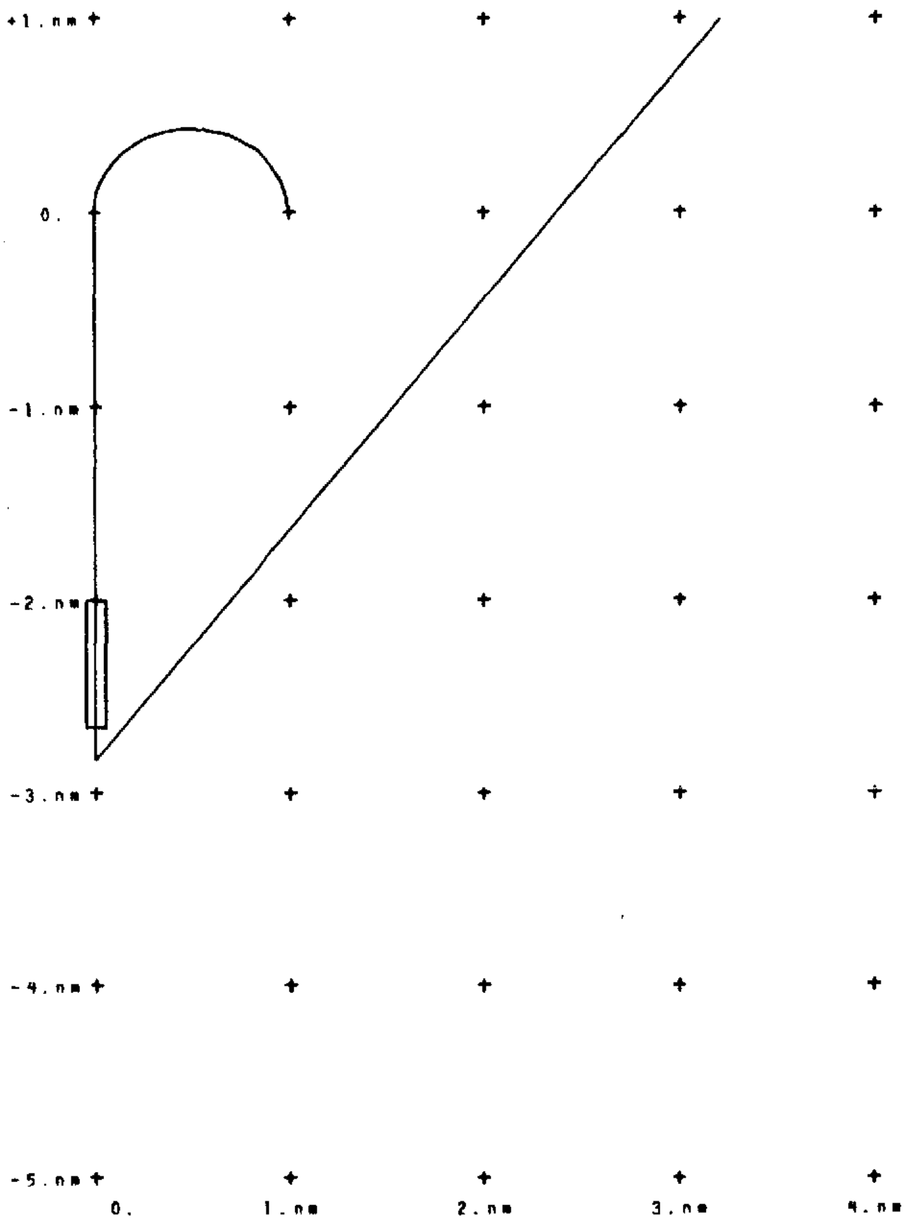


FIGURE B-32. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =2. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 95. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.

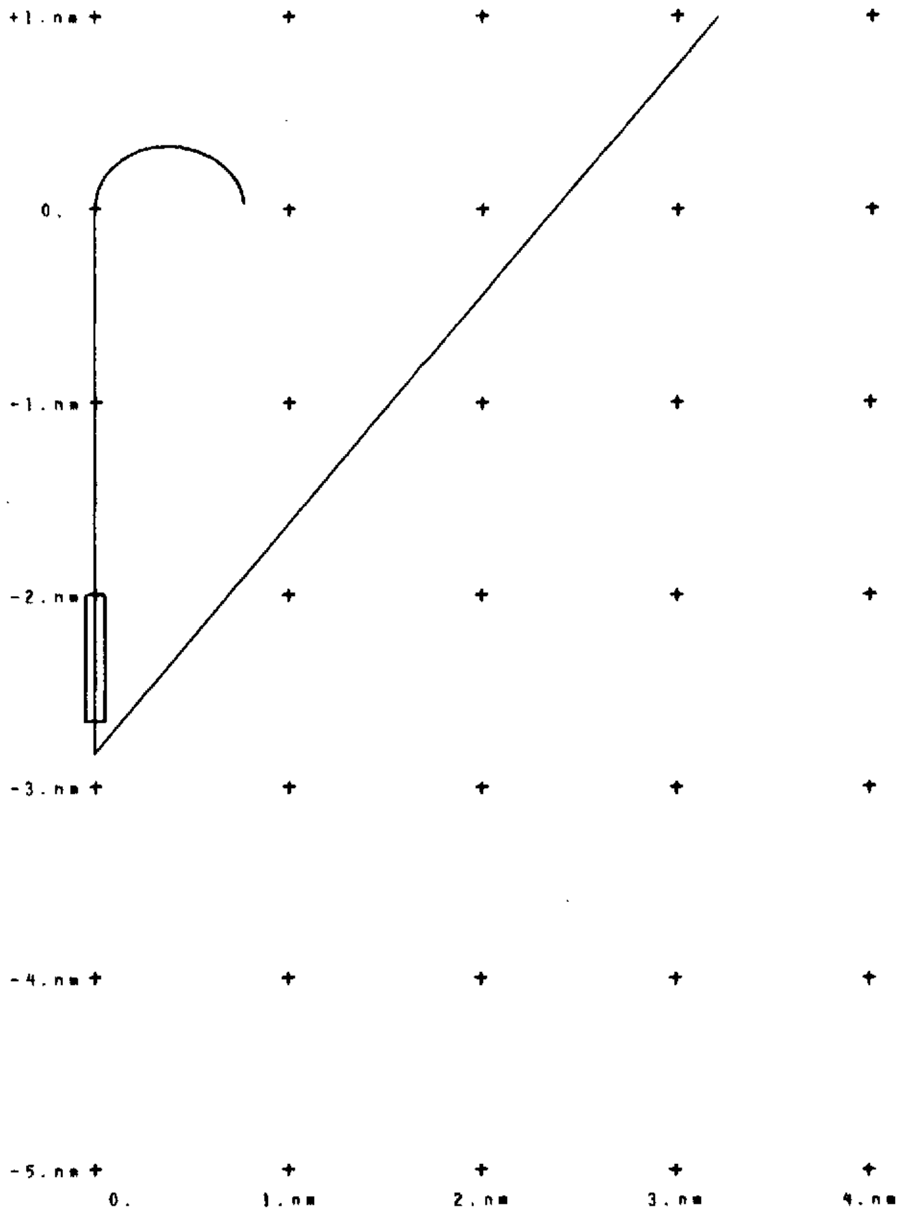
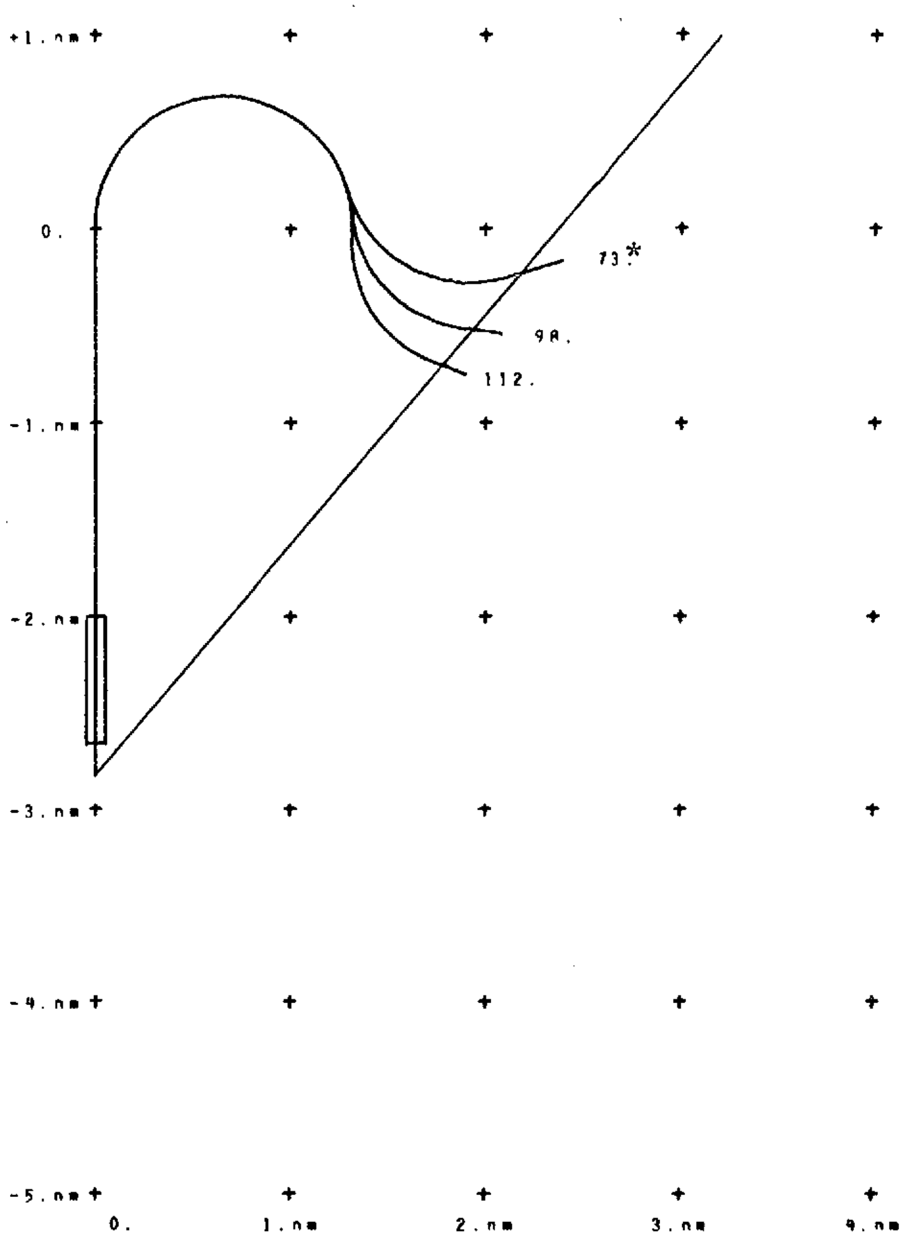


FIGURE B-33. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =2. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 80. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-34. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS

Common path length =2. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =15. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity =110. kn.
Wind velocity = 0. kn.
Wind direction = 0. deg.

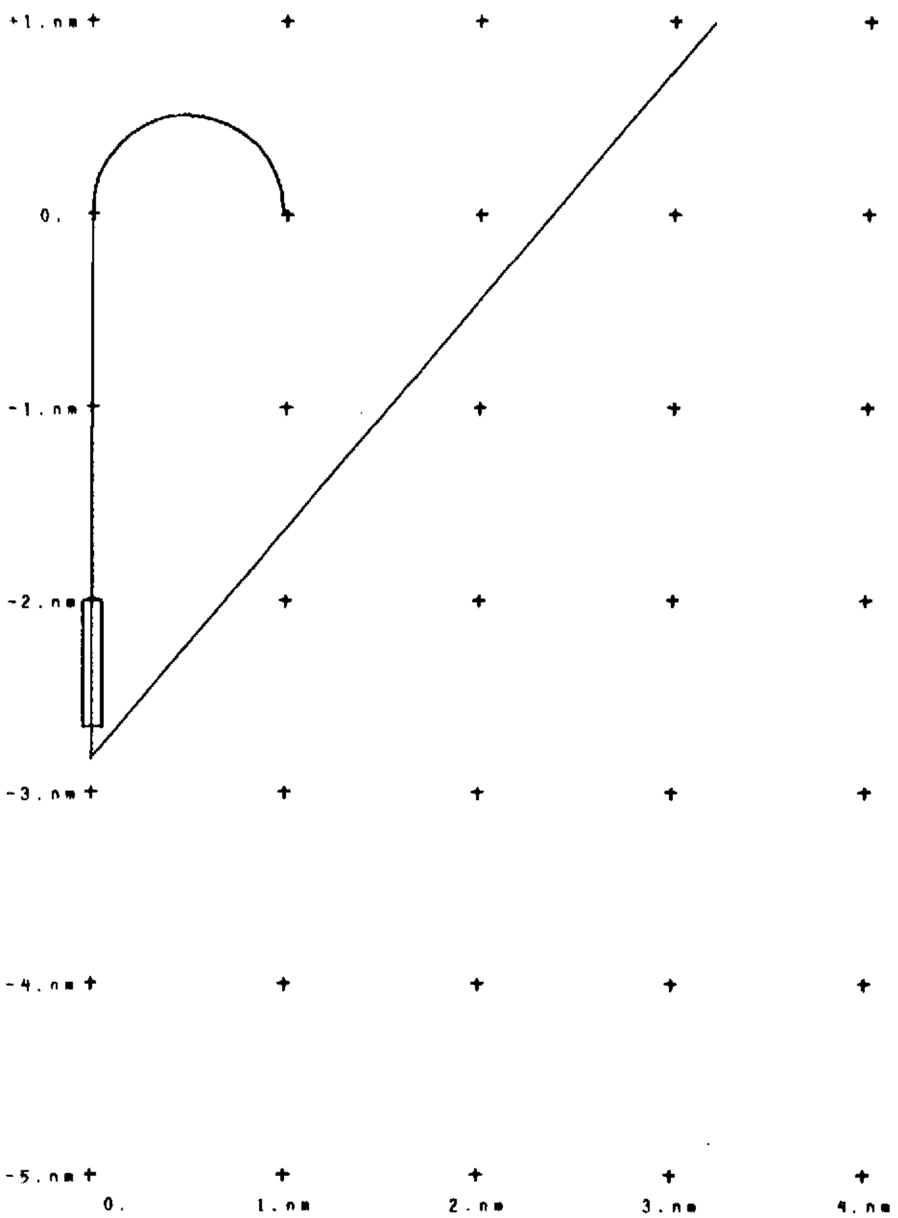


FIGURE B-35. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length = 2. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway = 1000. ft.
MLS Azimuth angle = 40. deg.
Aircraft bank angle limit = 15. deg.
Aircraft bank angle rate limit = 10. deg./sec.
Aircraft velocity = 95. kn.
Wind velocity = 0. kn.
Wind direction = 0. deg.

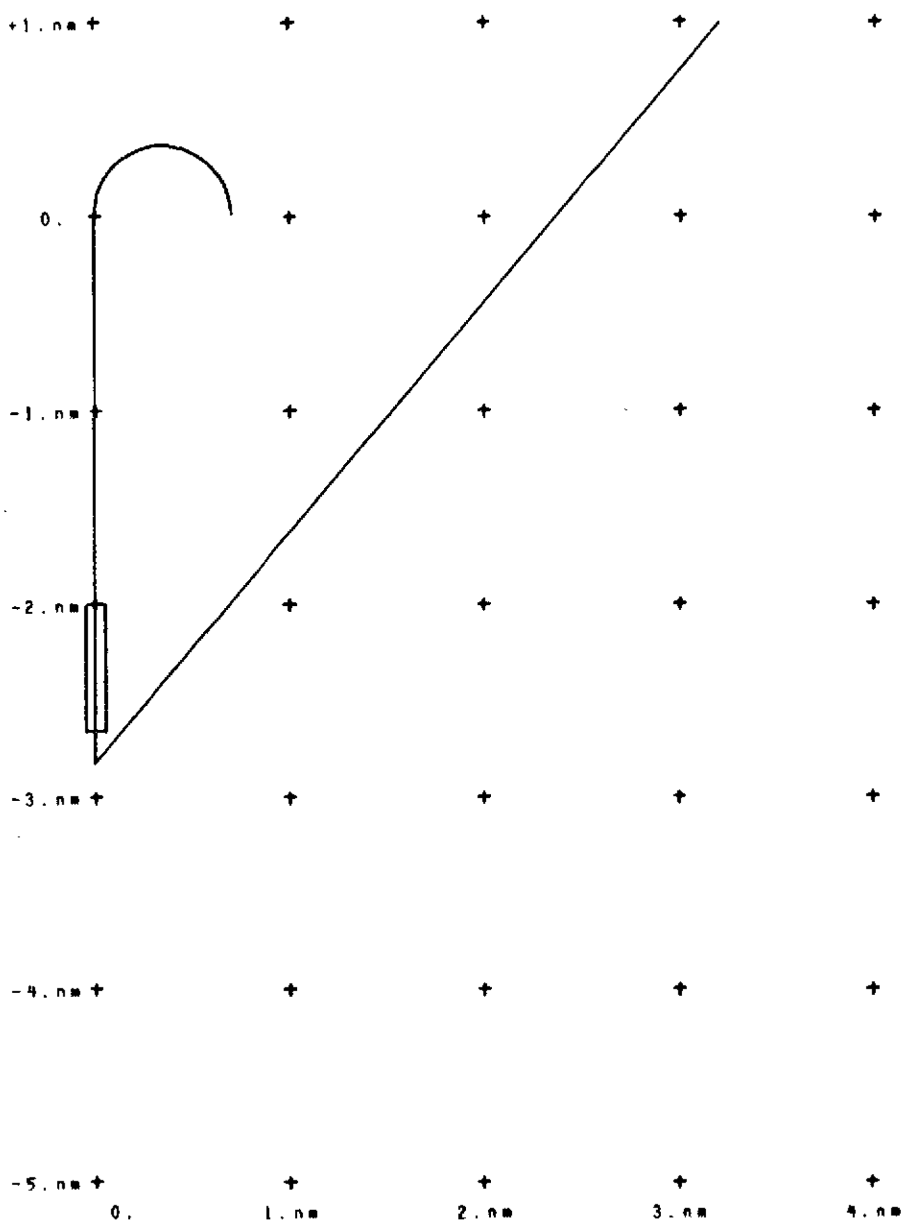


FIGURE B-36. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length	=2. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=40. deg.
Aircraft bank angle limit	=15. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	= 80. kn.
Wind velocity	= 0. kn.
Wind direction	= 0. deg.

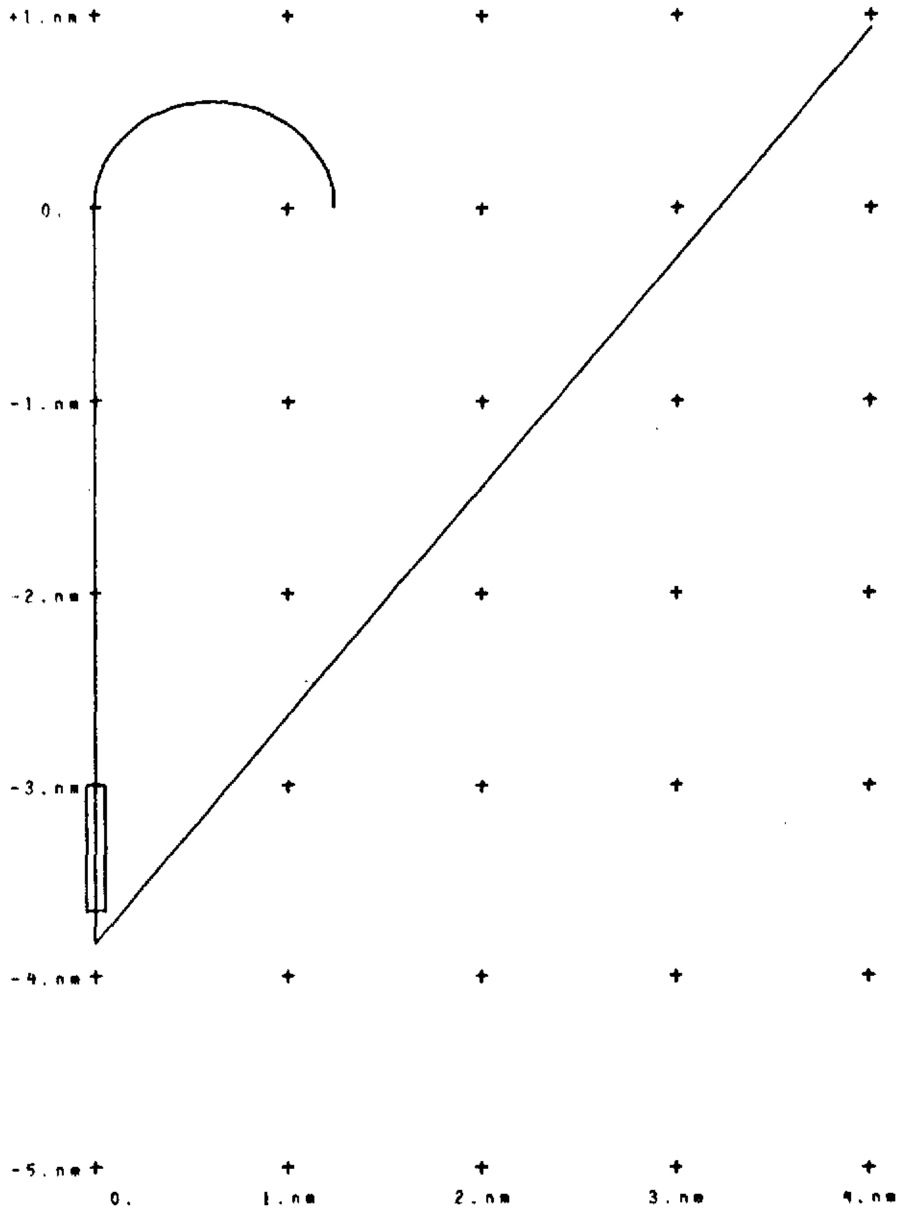


FIGURE B-37. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =3. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity =110. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.

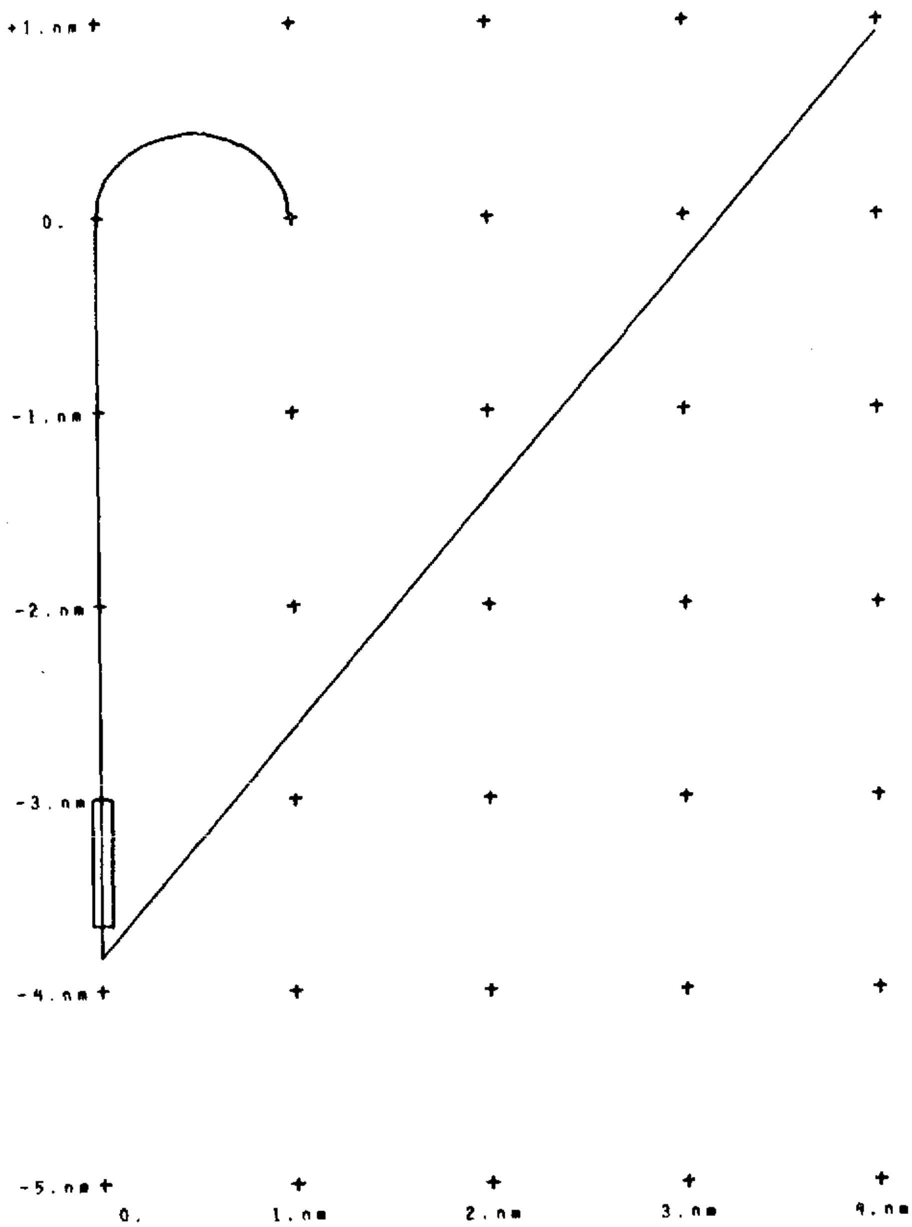


FIGURE B-38. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =3. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 95. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.

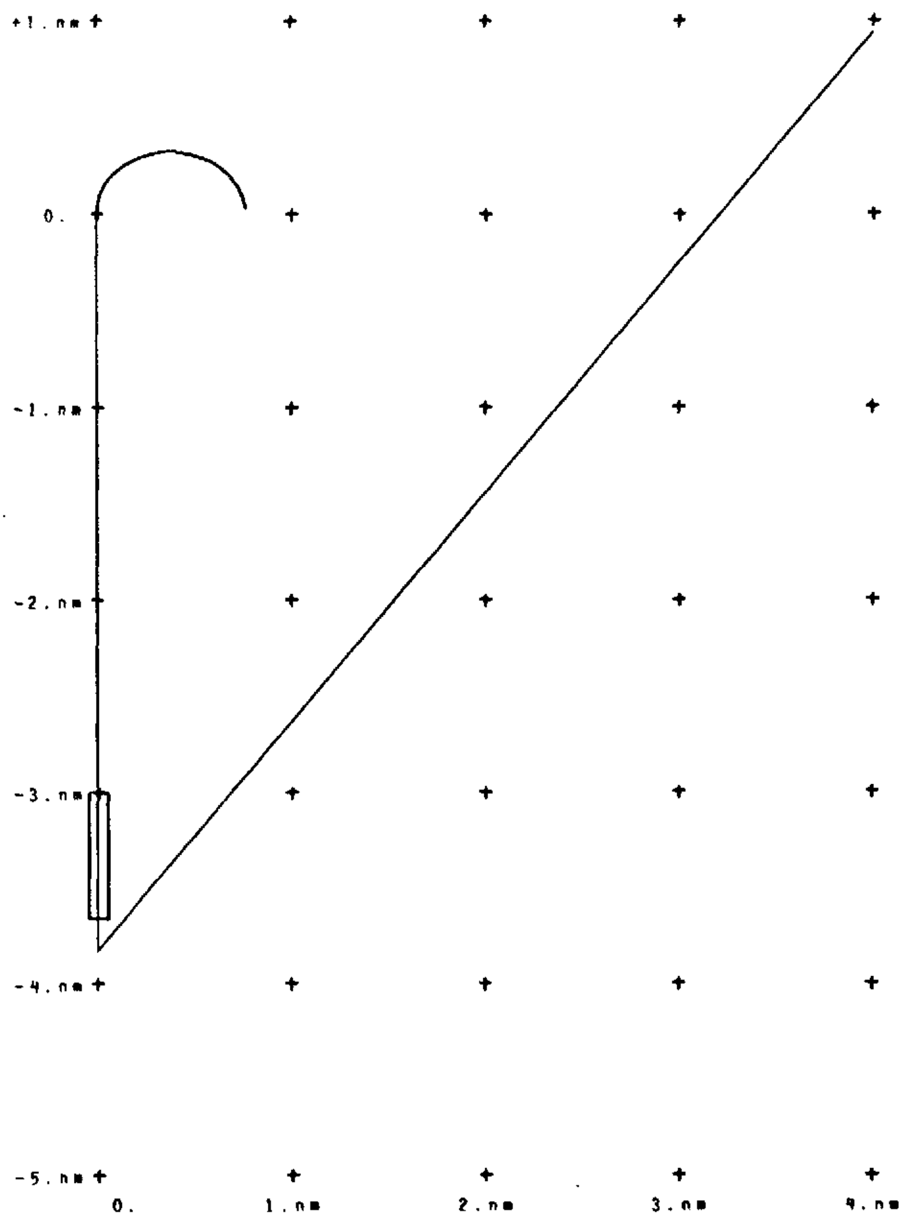


FIGURE B-39. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =3. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 80. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.

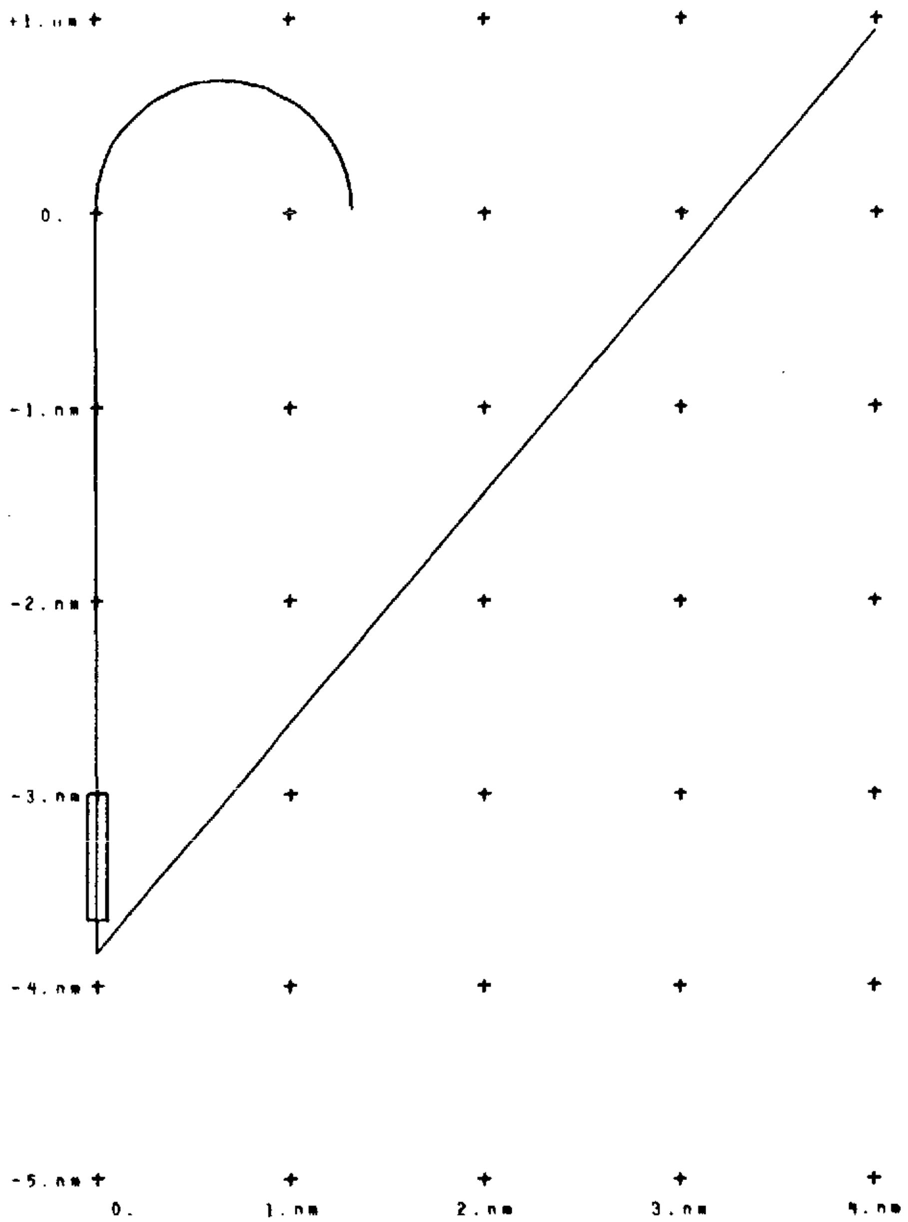


FIGURE B-40. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =3. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =15. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity =110. kn.
Wind velocity = 0. kn.
Wind direction = 0. deg.

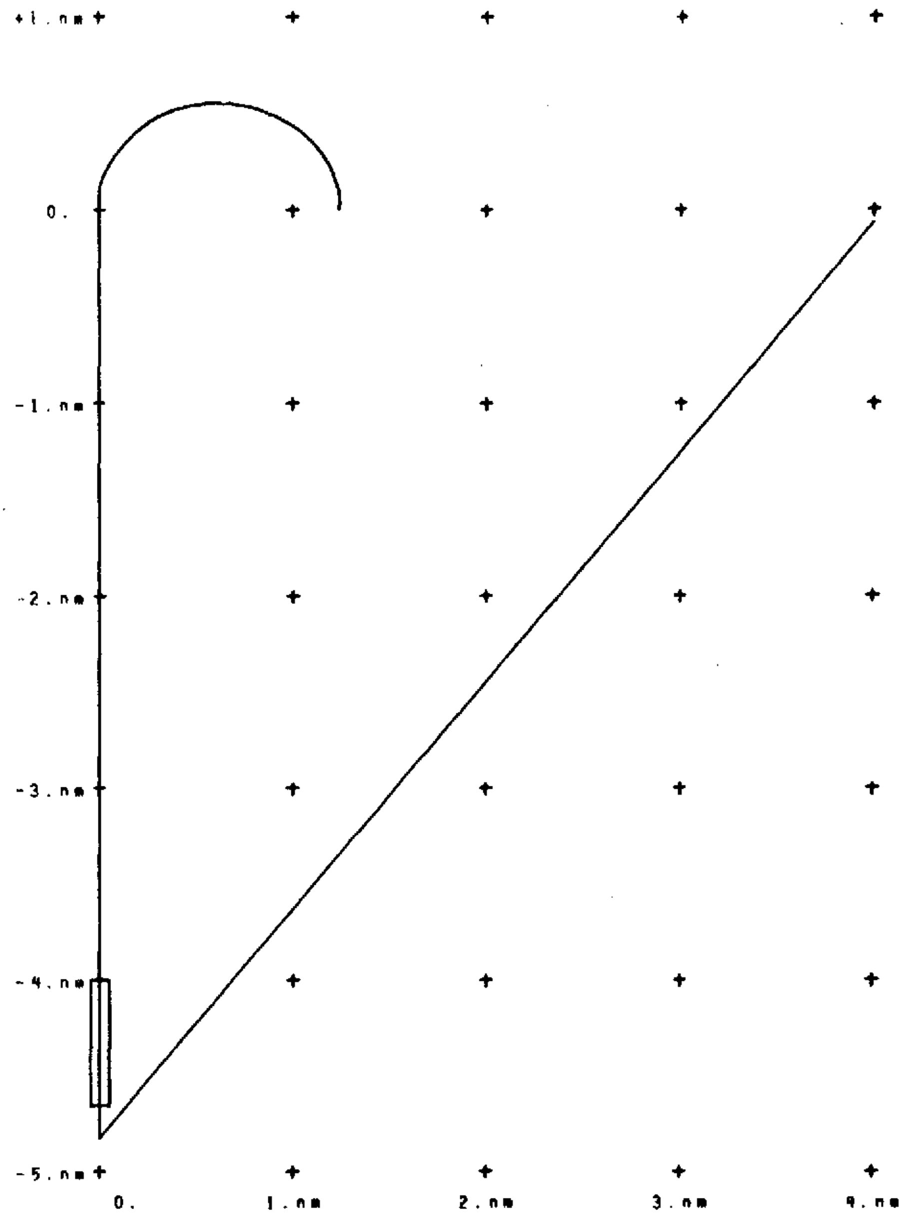


FIGURE B-41. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =4. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity =110. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.

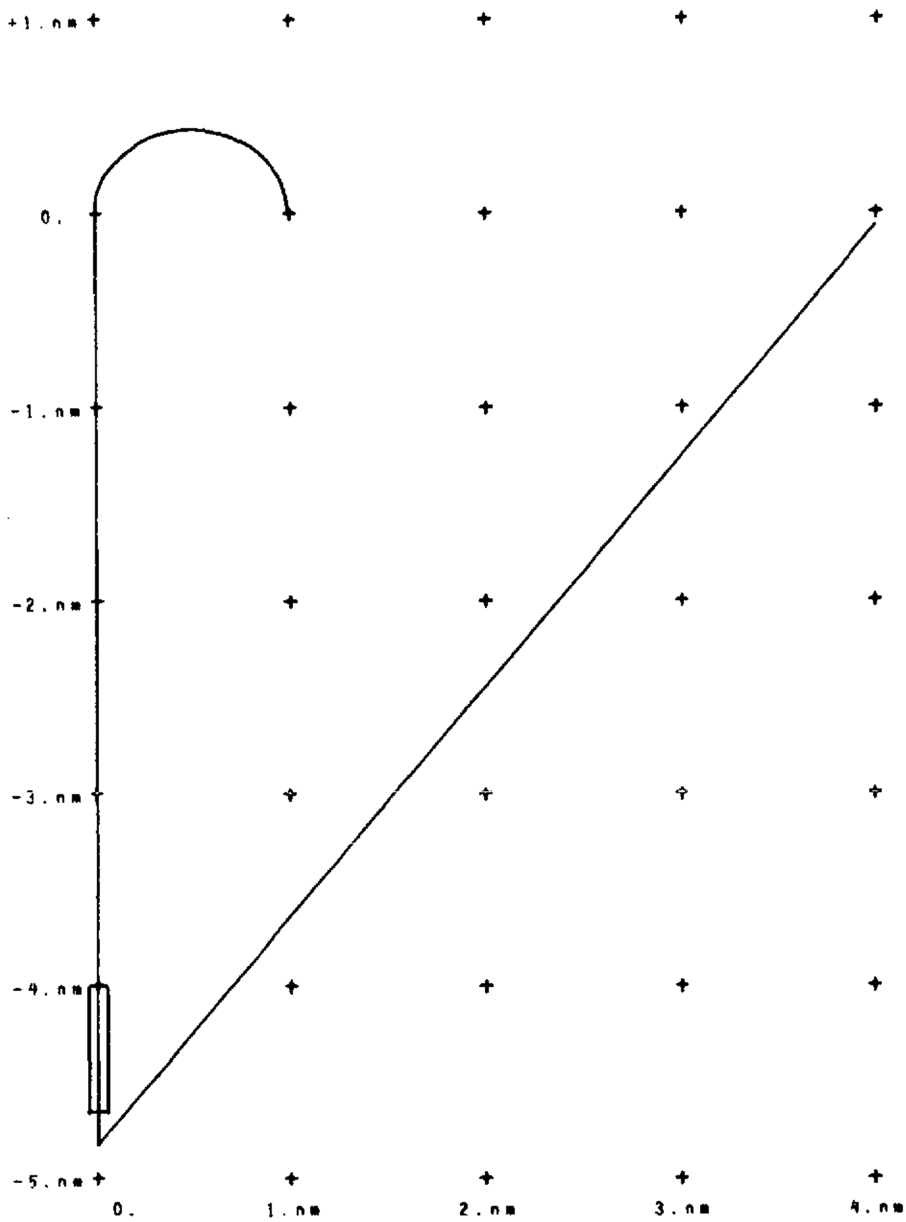


FIGURE B-42. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =4. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 95. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.

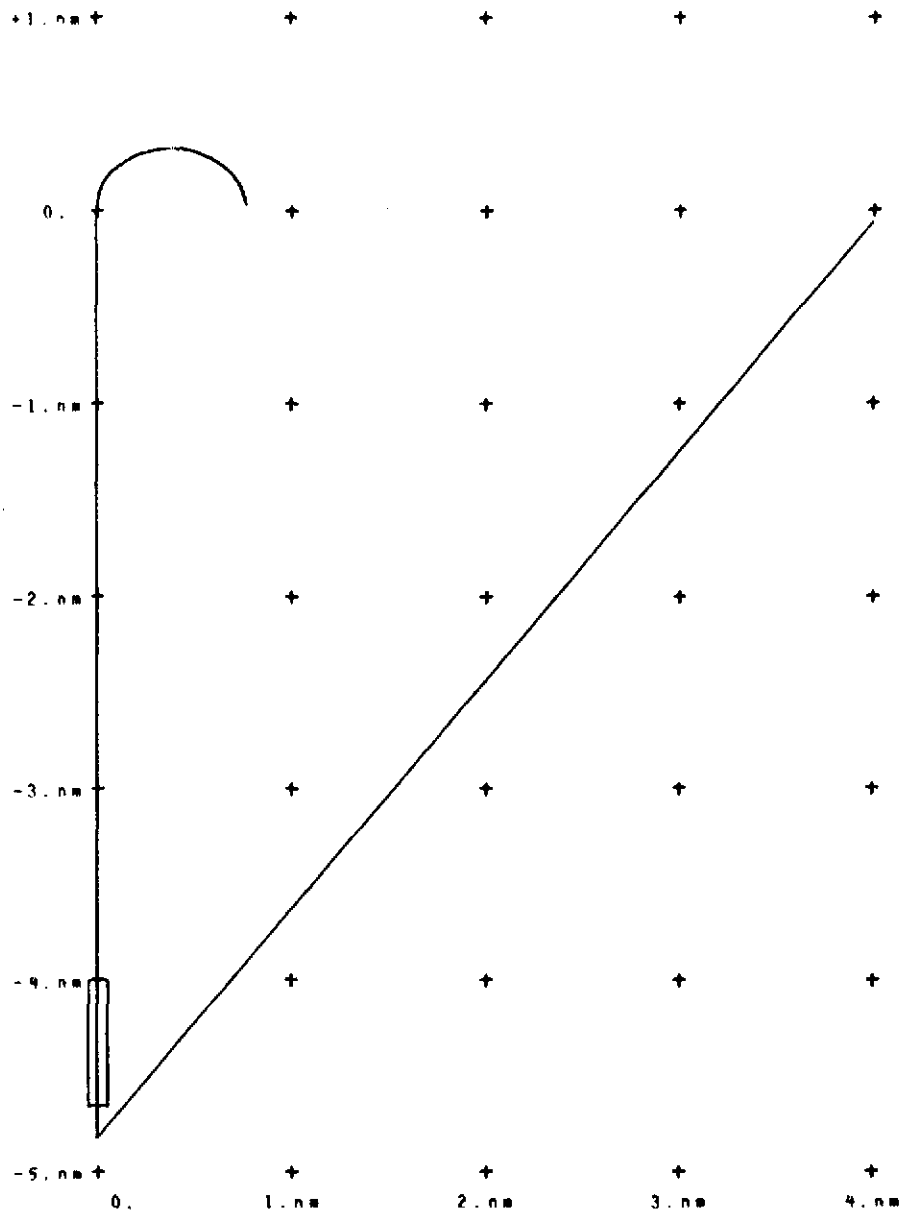


FIGURE B-43. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =4. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 80. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.

C3

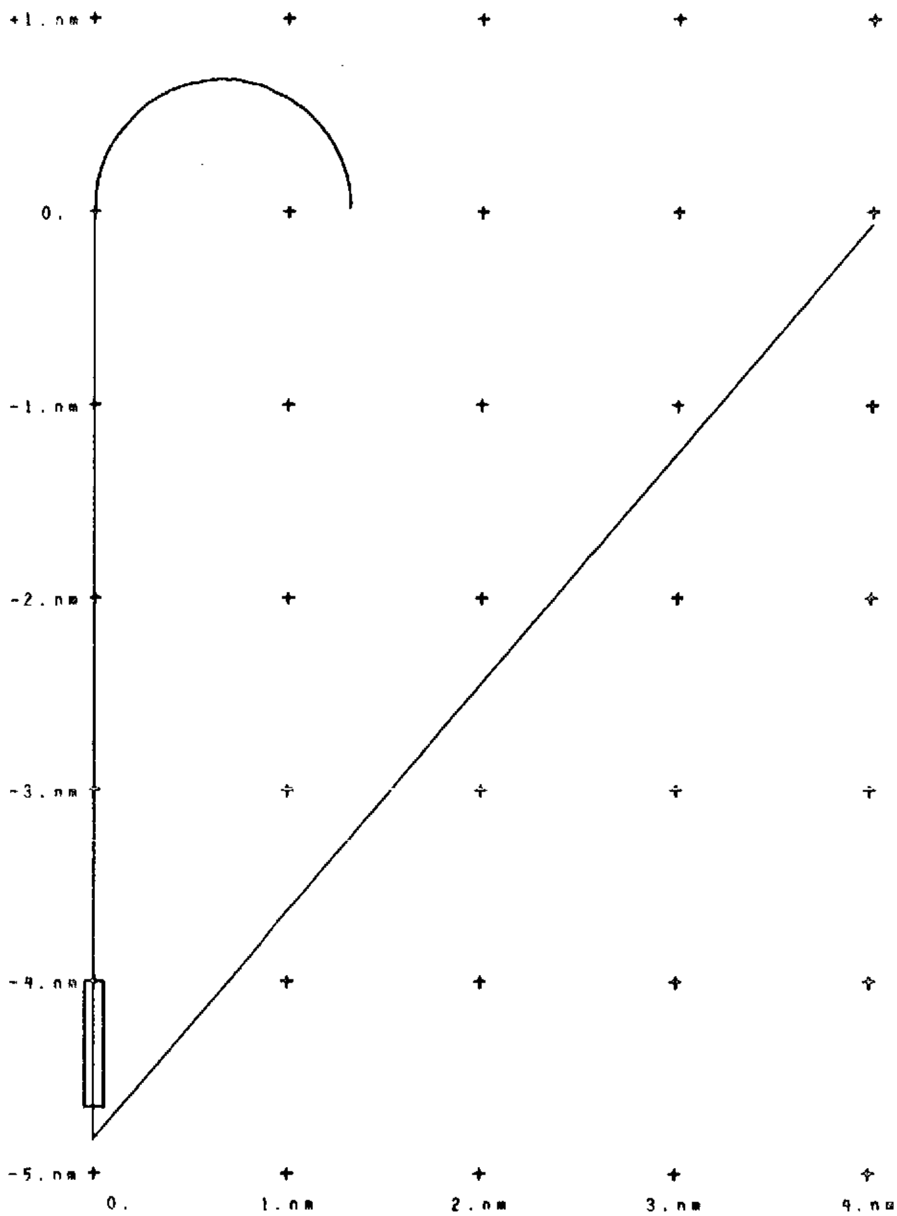
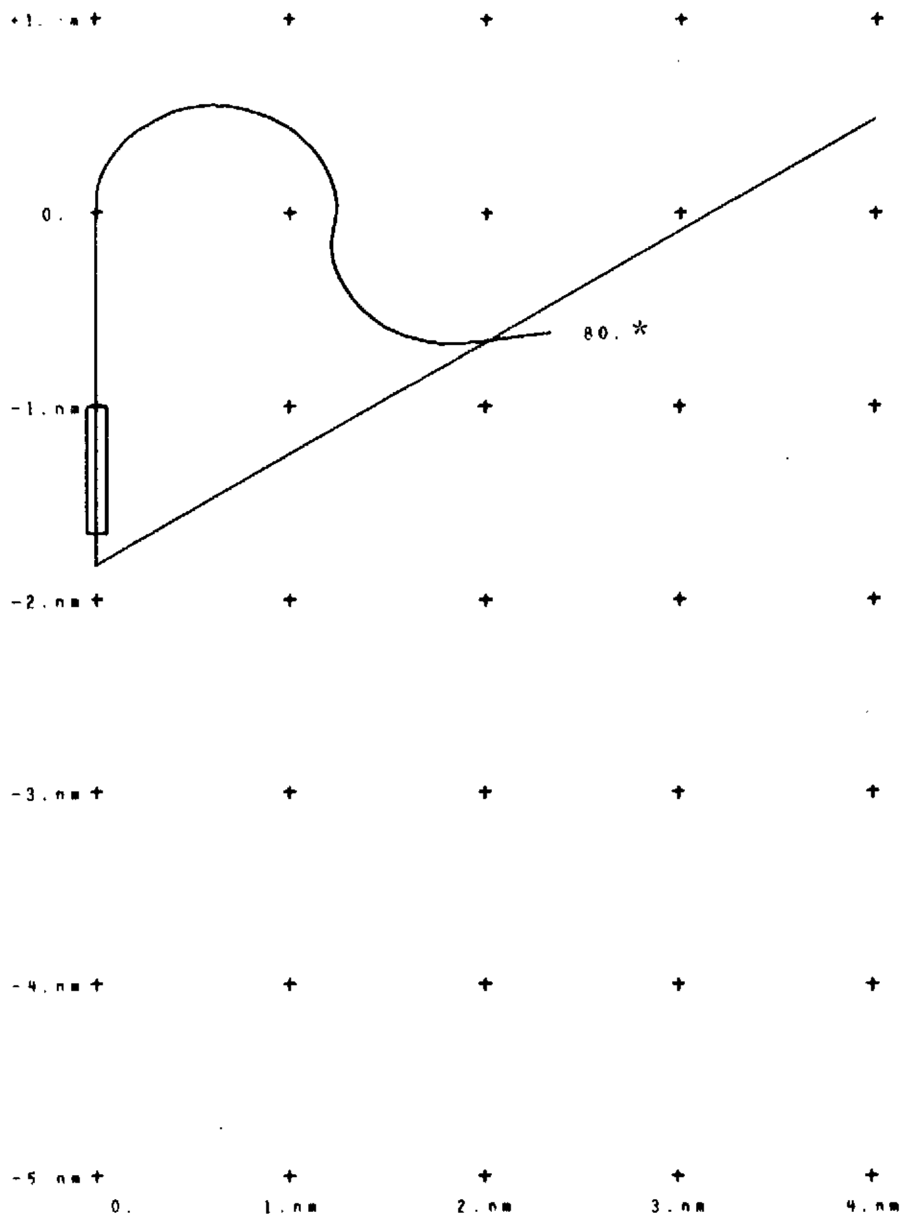


FIGURE B-44. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =4. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =40. deg.
Aircraft bank angle limit =15. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity =110. kn.
Wind velocity = 0. kn.
Wind direction = 0. deg.



* Initial inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-45. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length	=1. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=60. deg.
Aircraft bank angle limit	=25. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	=110. kn.
Wind velocity	=40. kn.
Wind direction	= 90. deg.

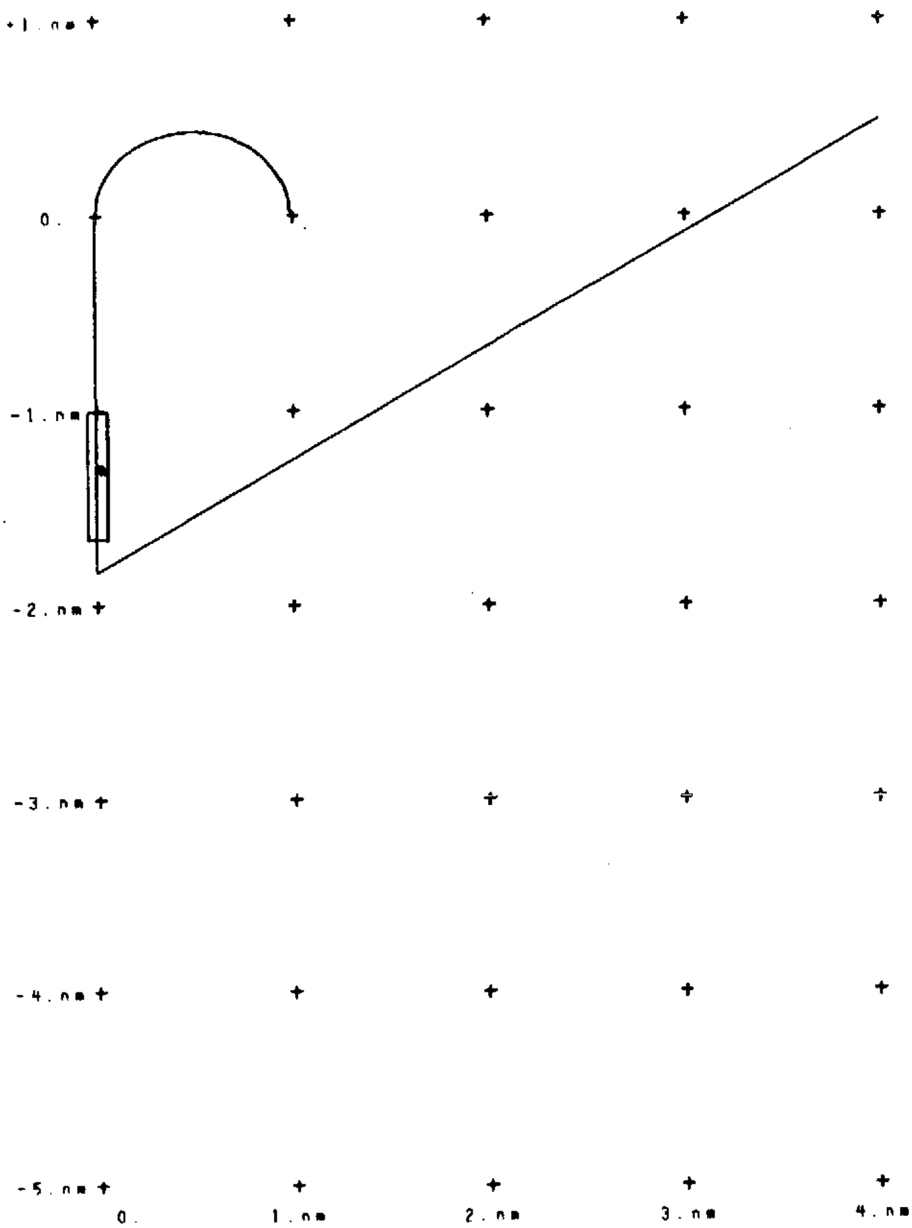


FIGURE B-46. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =1. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =60. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 95. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.

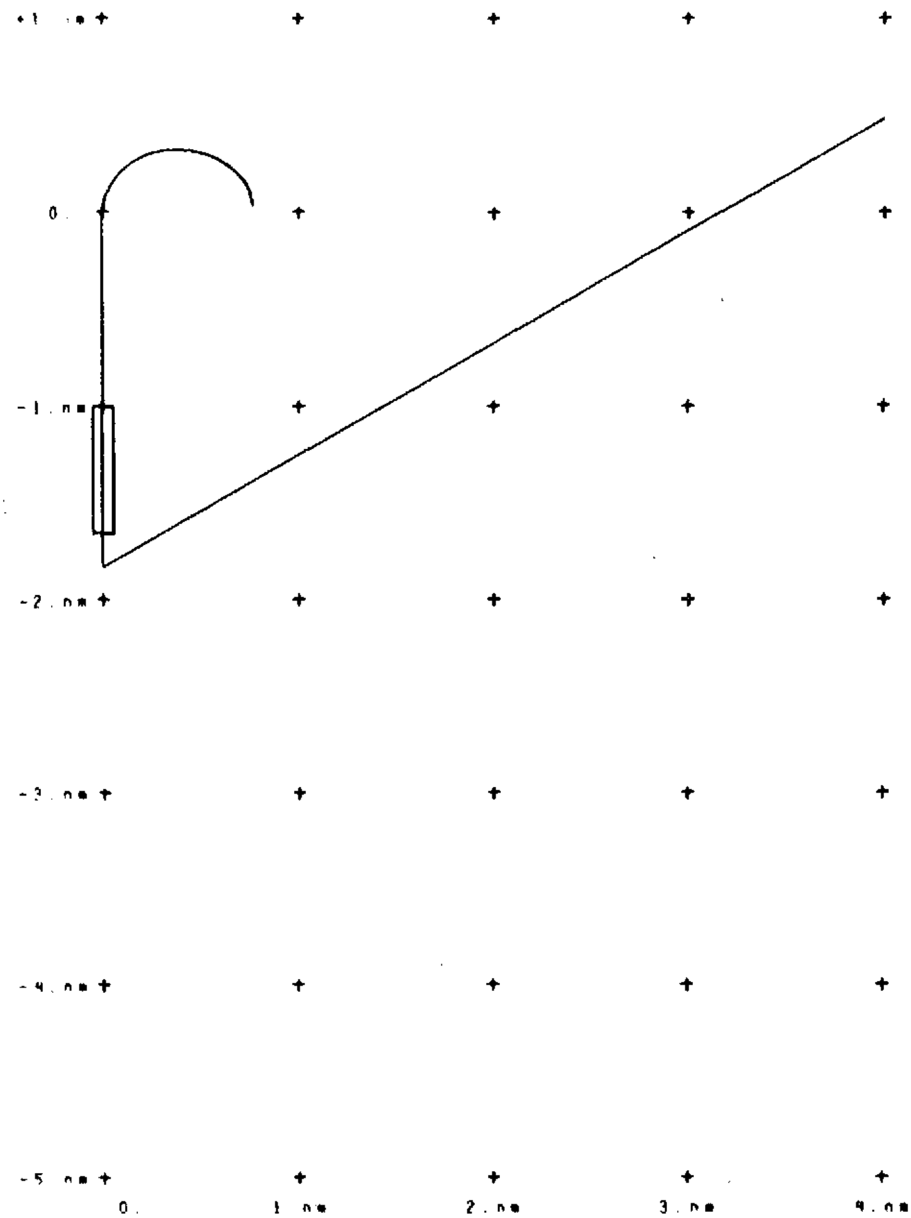
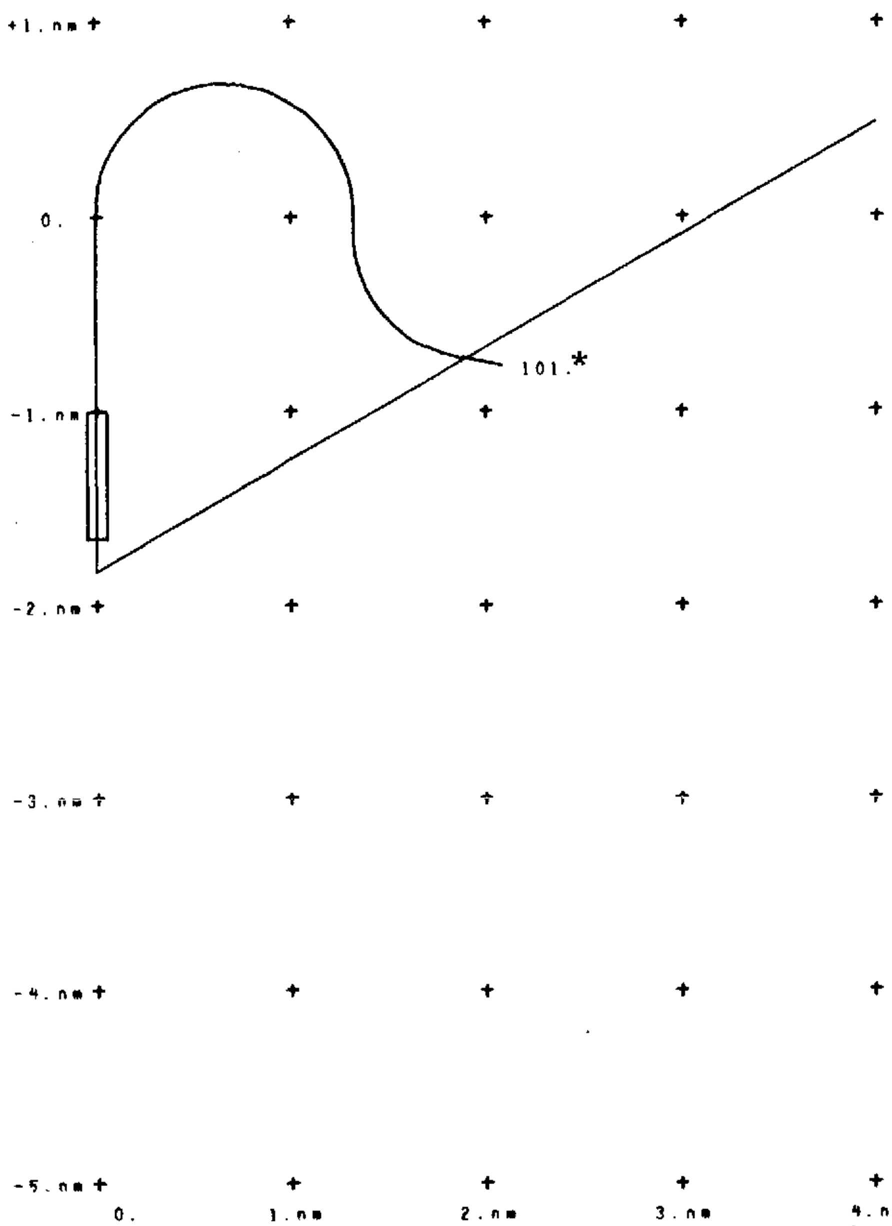


FIGURE B-47. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =1. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =60. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 80. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.



* Initial Inbound aircraft heading in degrees where the final heading is zero degrees.

FIGURE B-48. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length	=1. nm.
Runway length	= 4000. ft.
Azimuth siting beyond stop end of runway	=1000. ft.
MLS Azimuth angle	=60. deg.
Aircraft bank angle limit	=15. deg.
Aircraft bank angle rate limit	=10. deg./sec.
Aircraft velocity	=110. kn.
Wind velocity	= 0. kn.
Wind direction	= 0. deg.

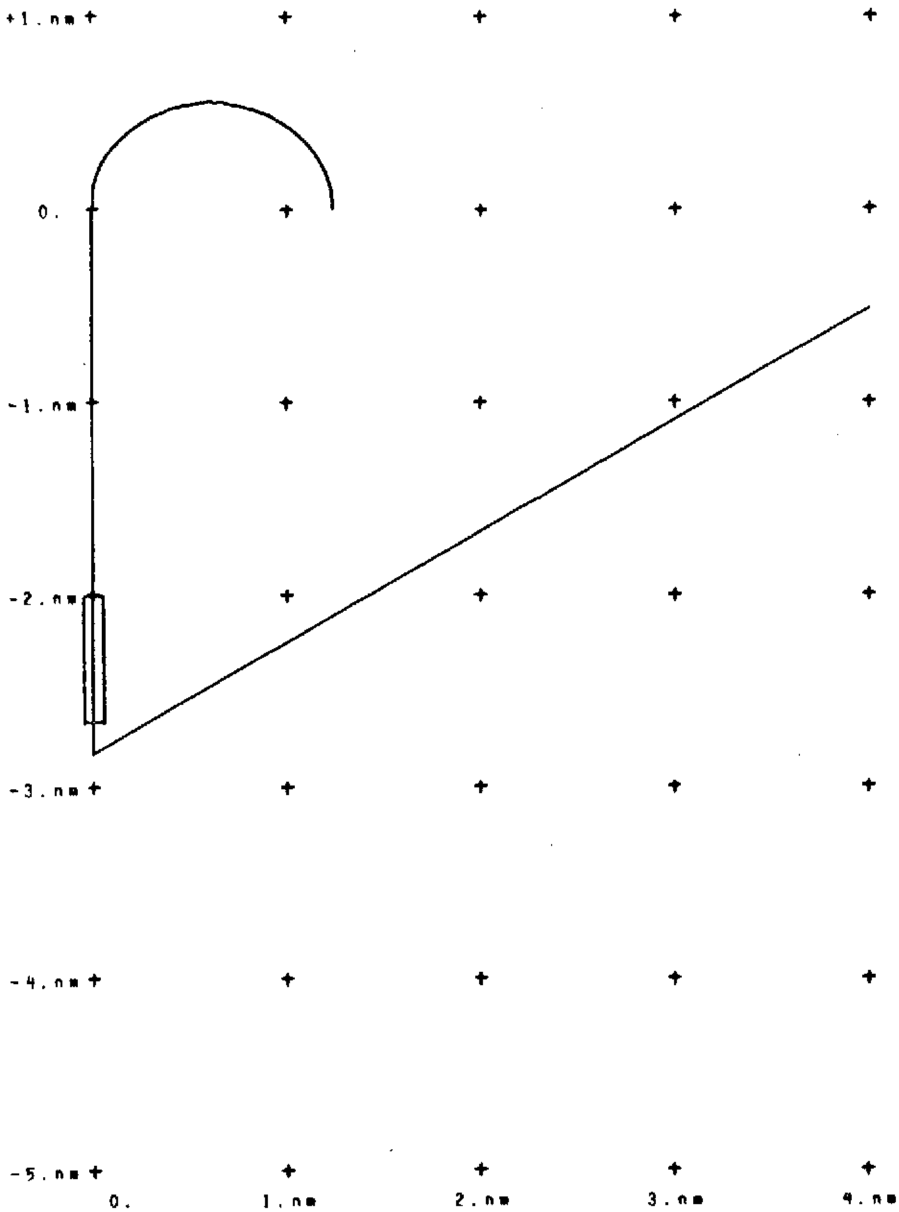


FIGURE B-49. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =2. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =60. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity =110. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.

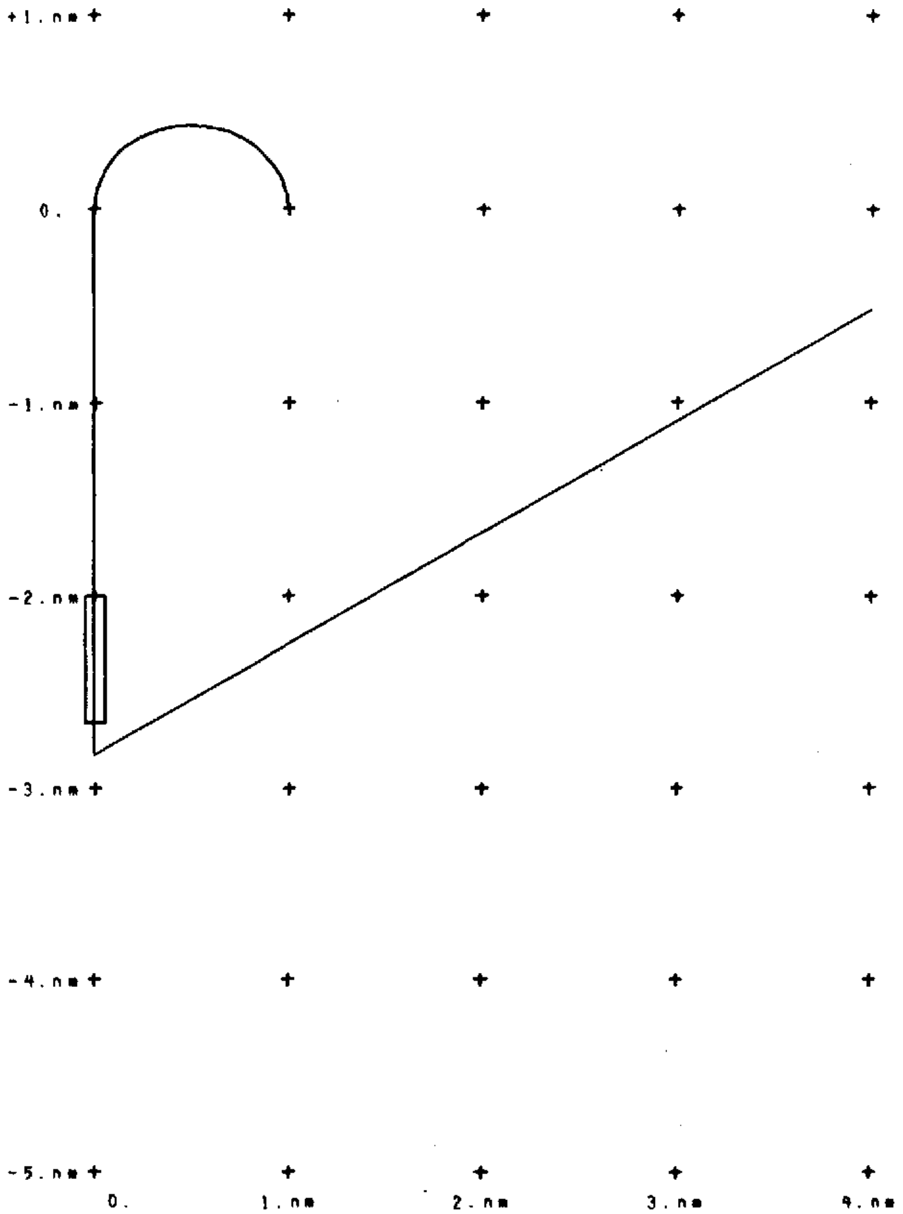


FIGURE B-50. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =2. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =60. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 95. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.

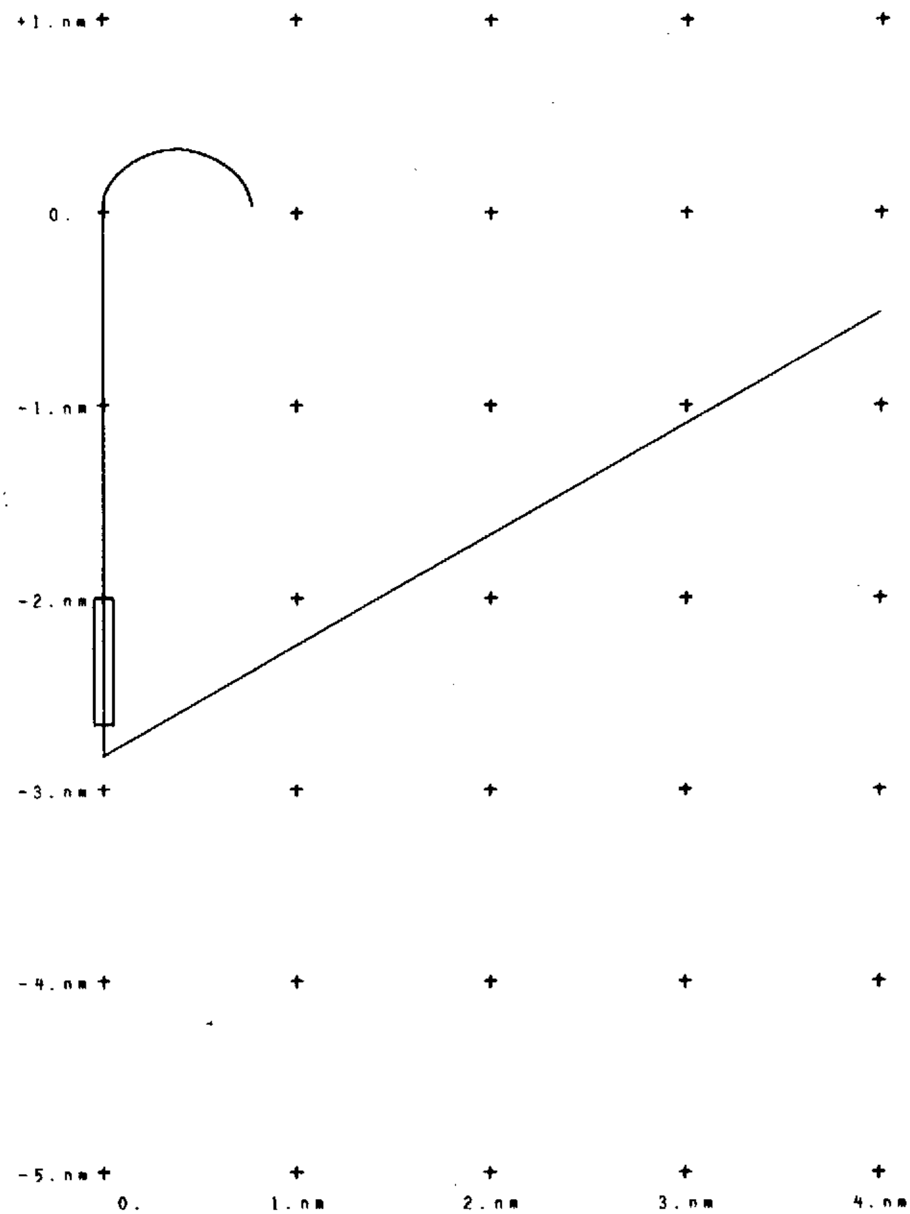


FIGURE B-51. MANUEVER CONSTRAINTS UNDER THE FOLLOWING CONDITIONS:

Common path length =2. nm.
Runway length = 4000. ft.
Azimuth siting beyond stop end of runway =1000. ft.
MLS Azimuth angle =60. deg.
Aircraft bank angle limit =25. deg.
Aircraft bank angle rate limit =10. deg./sec.
Aircraft velocity = 80. kn.
Wind velocity =40. kn.
Wind direction = 90. deg.